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# THE TESTING OF CONTINUOUS CURRENT MACHINES

# THE TESTING OF CONTINUOUS CURRENT MACHINES IN LABORATORIES AND TEST-ROOMS

*A PRACTICAL WORK FOR STUDENTS AND ENGINEERS*

BY

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**With 249 Illustrations**

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1905

# PREFACE

THIS work originated in a number of written instructions for making experiments in the machine-laboratories, which I used to give my students at the Municipal School of Technology in Manchester. The success which I had with these instructions has induced me to publish them in a completed and enlarged form.

Thus the work is intended for students at technical colleges and schools. Its purpose is to prepare the student for his laboratory work, to explain the purpose of the various experiments, and to give him exact instructions for carrying them out. Special stress has been laid on the introduction of characteristic examples; my experience has taught me that in most cases it is not so much the carrying out of an experiment, as its application for practical purposes, that offers the most difficulties to students.

The work is further intended both for electrical and mechanical engineers, who are engaged in test-room work, or in installing, starting, and supervising electrical machinery. With this object I have kept it more elementary than would probably have been necessary for advanced students. Notwithstanding, a knowledge of the principles of continuous current machines had to be assumed, and explanations referring to these principles

302131

have been given only in a few instances, such as armature-reaction, etc.

I am greatly indebted to my colleague, Mr. J. Lustgarten, M.Sc., for the great assistance he has rendered me in publishing the English edition of this work, and my thanks are due to him for the many suggestions he has offered.

C. KINZBRUNNER.

MANCHESTER,

*August*, 1904.

# CONTENTS

## CHAPTER I

## INTRODUCTION—INSTRUMENTS AND APPARATUS

PAGE

1. Switches . . . . . 4
2. Cut-outs . . . . . 9
3. Wires and Cables . . . . . 10
4. Starters and Regulators . . . . . 10
5. Shunt Regulators . . . . . 13
6. Loading Resistances and Methods of loading Generators and Motors 15
7. Measuring Instruments . . . . . 23

Sources of E.M.F. . . . . 29

## CHAPTER II

## RESISTANCE MEASUREMENTS

Armature Resistance . . . . . 31

Experiment No. I.—Measurement of the Armature Resistance . . 35

Contact Resistance . . . . . 40

Experiment No. II.—Measurement of the Contact Resistance between Brushes and Commutator . . . . . 41

The Brush Resistance . . . . . 45

The Total Armature Resistance . . . . . 46

Experiment No. III.—Measurement of the Total Armature Resistance . 46

The Field Resistance . . . . . 47

## CHAPTER III

## MEASUREMENT OF TEMPERATURES

General Remarks . . . . . 49

Measurement of the Temperature of Armatures . . . . 51

Measurement of the Temperature of Field Windings . . . . 53

Measurement of the Temperature of Commutators . . . . 54

## CHAPTER IV

## INSULATION MEASUREMENTS

PAGE

Measurement of Insulation Resistance . . . . . 55
Measurement of the Dielectric Strength . . . . . 61

## CHAPTER V

MEASUREMENT OF SPEED . . 64

## CHAPTER VI

## NO-LOAD CHARACTERISTICS

1. The Shunt Machine . . . . . 72
Experiment No. IV.—No-load Characteristic of a separately excited Shunt Machine . . . . . 73
Experiment No. V.—No-load Characteristic of a self-excited Shunt Machine . . . . . 78
Experiment No. VI.—No-load Characteristic of a Shunt Machine with separate constant-current excitation . . . . . 82
Experiment No. VII.—No-load Characteristic of a self-excited Shunt Machine . . . . . 87
Experiment No. VIII.—No-load Characteristic of a Shunt Motor . . 91
2. Remarks on the Self-excitation of Shunt Generators . . . 95
3. The Series Machines . . . . . 98
Experiment No. IX.—No-load Characteristic of a Series Machine . 99
4. The Compound Machine . . . . . 100

## CHAPTER VII

## LOAD CHARACTERISTICS

1. Shunt Generators . . . . . 103
Experiment No. X.—Load Characteristic of a separately excited Shunt Machine . . . . . 103
Experiment No. XI.—External Characteristic of a separately excited Shunt Dynamo . . . . . 110
Experiment No. XII.—External Characteristic of a self-excited Shunt Dynamo . . . . . 117
2. Shunt Motors . . . . . 121
Experiment No. XIII.—Load Characteristic of a Shunt Motor . . 121
Experiment No. XIV.—Speed Characteristic of a Loaded Shunt Motor 126

PAGE
3. Series Generators . . . . . 130
Experiment No. XV.—External Characteristic of a Series Generator . 130
4. Remarks on the Self-excitation of Series Dynamos . . . 135
5. Series Motors . . . . . 137
Experiment No. XVI.—Characteristic of a Series Motor . . . 137
6. Compound Machines . . . . . 144
Experiment No. XVII.—Characteristic of a Compound Dynamo . . 145
Experiment No. XVIII.—Determination of Series Turns for a Compound Dynamo . . . . . 150

## CHAPTER VIII

## MAGNETIC MEASUREMENTS

1. Determination of the Magnetic Leakage or Stray Coefficient . 154
2. Field Distribution and Potential Curves . . . . 155
3. Experimental Determination of Field Distribution Curves . . 158
4. Potential Curves . . . . . 161

## CHAPTER IX

## EFFICIENCY

Introduction . . . . . 163
1. The Electrical Efficiency . . . . . 164
2. The Total (Commercial) Efficiency . . . . . 167
3. The Direct Method . . . . . 169
(a) Mechanical Brakes . . . . . 170
(b) Magnetic or Eddy Current Brakes . . . . . 181
4. The Indirect Brake Method . . . . . 187
Experiment No. XIX.—Determination of Efficiency of a Dynamo by the Indirect Braking Method . . . . . 188
5. Calibration of an Auxiliary Motor . . . . . 191
6. The Indirect Method . . . . . 199
Experiment No. XX.—Determination of Efficiency of a Shunt Machine by the Indirect Method . . . . . 210
Experiment No. XXI.—Determination of the Efficiency of a Series Machine by the Indirect Method . . . . . 221
Experiment No. XXII.—Determination of Efficiency of a Compound Dynamo by the Indirect Method . . . . . 231
7. Additional Losses . . . . . 232
8. The Auxiliary Motor Method . . . . . 233
Experiment No. XXIII.—Determination of Efficiency by the Auxiliary Motor Method . . . . . 234

PAGE

9. The Hopkinson (Differential) Method . . . . . 238
(a) Hopkinson Test with Two Parallel Connected Machines . 238
(b) Hopkinson Test with Series Connected Machines . . . . 240
10. The Direct Electric Method . . . . . 241
Experiment No. XXIV.—Measurement of Efficiency of a Continuous Current Rotary Transformer . . . . . 242

## CHAPTER X

## THE SEPARATION OF LOSSES

Introduction . . . . . 244
1. Separation of Losses by Means of a (Calibrated) Auxiliary Motor 245
Experiment No. XXV. . . . . 245
2. Separation of Losses by Dettmar's Method . . . . . 253
Experiment No. XXVI. . . . . 253
3. The "Inertia" Method . . . . . 267
Experiment No. XXVII.—Separation of Losses by the "Inertia" Method 269

## CHAPTER XI

## PRACTICAL TESTING OF CONTINUOUS CURRENT MACHINES

Introduction . . . . . 274
1. American Institute of Electrical Engineeers (Report of Committee of Standardization) . . . . . 274
2. Shop Tests . . . . . 292
3. Shunt Generators . . . . . 293
4. Shunt Motors . . . . . 301
5. Series Generators . . . . . 303
6. Series Motors . . . . . 304
7. Tram Motors . . . . . 308
8. Compound Generators . . . . . 311

## APPENDIX

THE INSTALLATION, CARE, AND MAINTENANCE OF ELECTRIC MACHINES . . . . . 313

INDEX . . . . . 325

# CHAPTER I

## INTRODUCTION

It is important that experiments made in the laboratory or test-room be carried out in a systematic manner, and the results carefully recorded. Without these conditions, the experiment, however carefully prepared, is of little value. If thoroughly prepared, a useful result will often be attained, even if it is impossible to obtain a large number of readings.

Before commencing an experiment one must be perfectly clear about the method to be pursued, and whether it will really lead to the result desired. A complete diagram of the electrical connections should be made, and it is not advisable to copy this from the diagrams given in this work, but an independent sketch should be prepared, which may afterwards be compared with that given in connection with the particular exercise.

Next, the various instruments, apparatus, cables, and cable connections are chosen and connected together. In making the connections between two cables, the practice of twisting the copper strands round each other must never be adopted but proper connectors be used. Bad connections of this kind are not only injurious to the cables, but may in some cases prove to be dangerous. To cite an example: Suppose an imperfect connection exists in the field circuit of a shunt motor, and this is severed owing to the wires being disturbed, the armature would "run away," and might burst. The connectors should preferably be well coated with an insulating varnish, or wound with insulating tape.

For joining up instruments and apparatus, the terminals of the latter can either be permanently connected to cables whose free ends are exposed for further connection with cable-shoes, or it is well to have a number of short cables—preferably of a flexible kind—provided with cable-shoes that can be fitted to the terminals of apparatus.

It will frequently save time and prevent damage to instruments

to have the ends of the mains marked + and −. This applies also to measuring and other instruments.

The connections should be systematically arranged. A muddle of cables and wires must be avoided. Time will be saved by observing this rule, especially if an error has been made in the connections. If not confused there will then be no difficulty in tracing the leads and remedying the mistake.

Sometimes two different arrangements of the connections are required in one experiment. It is then better to prepare the connections so that the change may be readily made. This is especially of importance when the temperature of the machinery under test is above that of the room. No time must be lost so as to secure the two measurements under the same temperature conditions.

In every experiment the main circuit requires a switch and fusible cut-out. These may be either **single** or **double pole**, in many cases the latter being preferable. The fusing current of the wire of the cut-out should be about 25 per cent. greater than the maximum reached in the experiment. The shunt circuit of motors must not contain a cut-out, but should be provided with an ordinary or special type of field switch. On starting a shunt motor the field circuit must first be closed, and the main circuit afterwards. When the motor has to be stopped, the order is reversed—the shunt circuit is broken last. With **motor starters** the closing and breaking of the field circuit is performed in the right order in the starter itself. The greatest care must be taken when the field circuit of a shunt motor is to be broken. **Shunt regulators** for motors must not have a point on which the circuit is broken.

Before starting the experiment it is as well to make sure that the resistances are large enough and the instruments of sufficient range. This may be ascertained by a preliminary test, without recording any readings. Otherwise, in the course of the experiment, the resistances selected may prove to be too small, or the pointer of an instrument sticks, which would of course necessitate a repetition of the experiment.

A **blank schedule** should be prepared so that the results of the experiments may be systematically recorded. The date of the experiment, and statements regarding the Maker's number, type, output, voltage, speed, etc., of the machine should be noted as far as they can be ascertained from the name plate. The exact diagram of connections must be drawn on the record sheet, and the types and numbers of the instruments used, as well as the names of the observers, be stated.

It is advisable that everything be put down on the record sheet, and nothing, not even auxiliary calculations, etc., written on separate

pieces of paper. Corrections that have to be applied to the readings, etc., require also scheduling.

As a rule, it may afterwards prove useful to have noted the temperature of the air of the laboratory or test-room at the time of the experiment.

When all the above preparations have been made, it must be next settled which instruments are to be read by the respective observers. With most experiments, two, and in some cases three or more observers are required. Each must observe his instrument, not only at the time when the reading is required, but continually throughout the experiment. This enables him to obtain a correct reading even if the pointer vibrates. After some practice, the mean position about which the pointer swings can be read off with great accuracy.

The readings of the respective instruments must naturally be taken simultaneously, and it is therefore desirable for one of the observers to indicate the exact moment when the reading should be taken by the help of a whistle or bell. For example, in determining the relation between the terminal pressure and load (viz. the current) of a generator for constant speed, the observer who measures the speed should give the signal, and adjust the speed if necessary.

With reference to the number of readings to be taken, it is essential that they be neither too near together nor too far apart. The examples given in this volume in connection with the various tests will be a guide. In the case of experiments taking a long time, it is recommended to plot the curves during the course of the experiment, the advantage lying in the fact that points which do not seem to be quite correct can be redetermined.

Whenever possible, the readings of instruments are to be taken to the tenth part of a division. For example, if one division represents one volt, then readings must be estimated to the tenth of a volt. Such readings will generally be correct to about two or three tenths of a division. Readings, accurate to a single tenth, are only possible with instruments provided with a mirror, whose deflection is read off on a scale. The percentage accuracy of the readings of the various instruments employed in one experiment should be the same. For instance, it is useless in measuring resistance to read the values of the current accurately to 0·1 per cent. if the voltage is measured with an accuracy of 1 per cent. only.

At the end of the experiment all switches should be opened, and, as a rule, the connections not destroyed until the results have been calculated.

# INSTRUMENTS AND APPARATUS

In the following a short description is given of instruments and apparatus required for the various experiments, namely—

1. Switches,
2. Cut-outs,
3. Wires and Cables,
4. Starters and Regulators,
5. Shunt Regulators,
6. Loading Resistances and Methods of loading Generators and Motors,
7. Measuring Instruments.

At the end of the chapter a few words will be said about the sources of electrical energy used in laboratories and test-rooms.

## 1. Switches

Switches serve the following purposes: Closing and breaking a circuit, changing from one circuit to another, and reversing the

FIG. 1.

FIG. 2.

direction of the current in a circuit. They may either be single or double pole. Typical constructions of switches are shown in Figs. 1 and 2. Generally types of switches are preferred in which the hinged part is not used for carrying current. For voltages of 200 and upwards, quick-break switches should be employed (see Fig. 3). In switching off, when the handle is pulled, a spring is first stretched to a certain extent depending on the position of a stop; after this the knife is

drawn out of the contacts, when the friction between the knife and contacts acts against the tension of the spring. Finally, the knife leaves the contacts, and the tension of the spring now causes a quick break of the circuit (see Fig. 3).

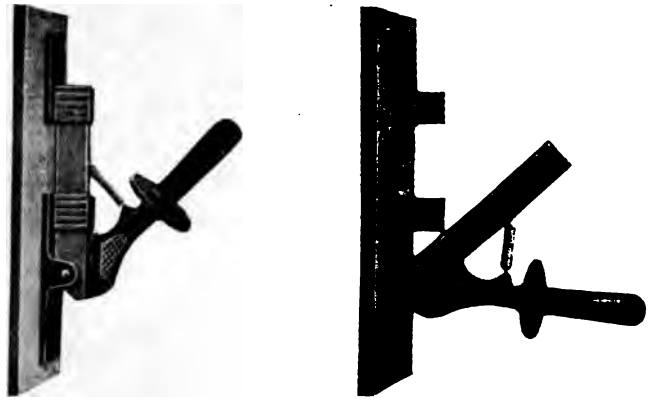


FIG. 3.

In subsequent diagrams of connections single and double pole switches will be represented as shown in Figs. 4 and 5.

The diagram of a **throw-over switch** for changing over from one circuit to another, is shown in Fig. 6. With a switch of this type the width of the lever contact may be either smaller or larger than

FIG. 4.

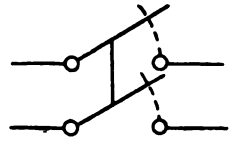


FIG. 5.

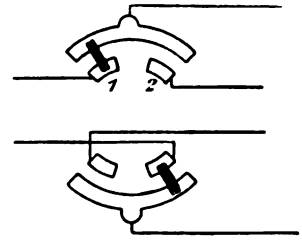



FIG. 6.

the distance between the contacts 1 and 2. In the first case the circuit is broken; in the latter, short-circuited for a moment, in turning the lever from position 1 to 2. This kind of switch must only be employed in circuits, in which a momentary short circuit

causes no damage. Figs. 7 and 8 indicate two types of these switches. To this type of switch belong also **voltmeter switches** used for measuring the voltage between different points by means of one

FIG. 7.

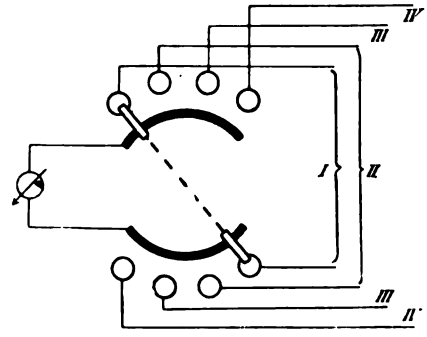



FIG. 9.

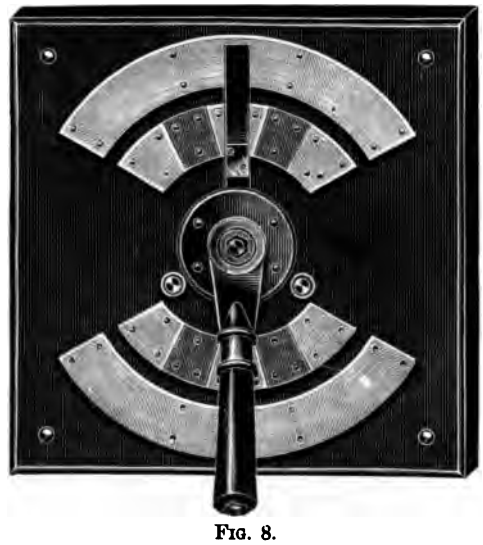


FIG. 8.

voltmeter. A diagram of a voltmeter switch is given in Fig. 9, whilst Fig. 10 represents one of the most usual arrangements.

For reversing the direction of current in a circuit **double-pole** switches are employed, as shown diagrammatically in Figs. 11–13.

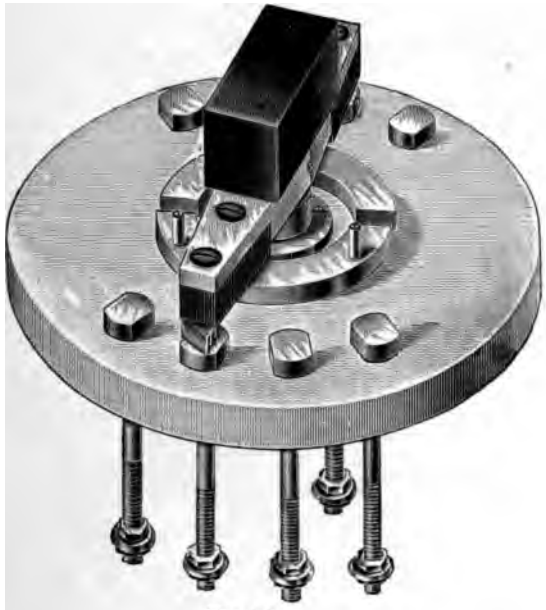


FIG. 10.

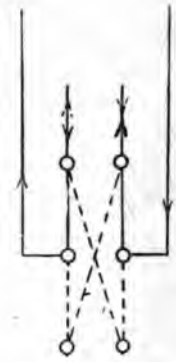


FIG. 11.

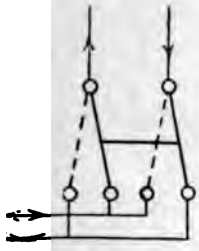


FIG. 12.

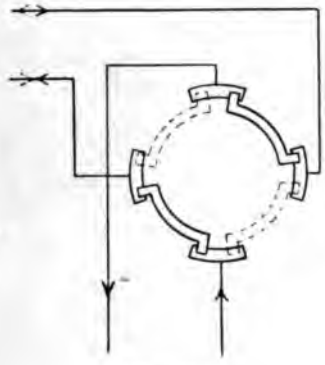


FIG. 13.

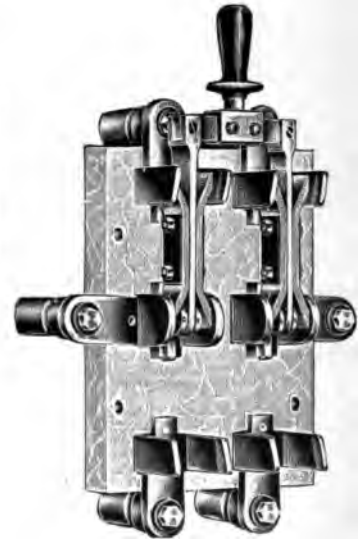


FIG. 14.

With these switches too, in throwing over, either an interruption of the current or a short-circuit must take place. The construction of two-pole throw-over switches is shown in Figs. 14–16.

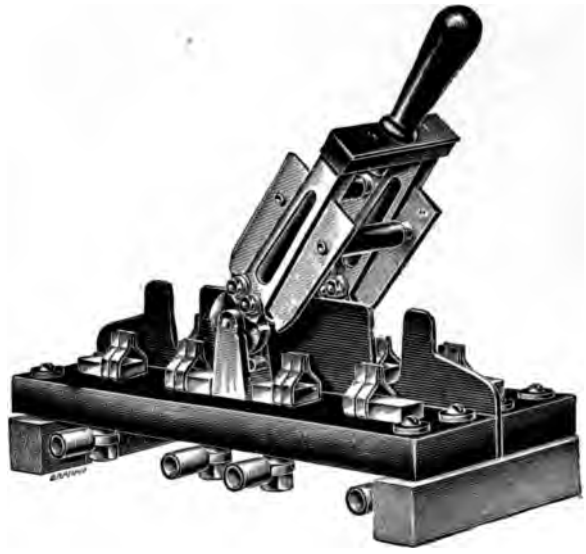


FIG. 15.

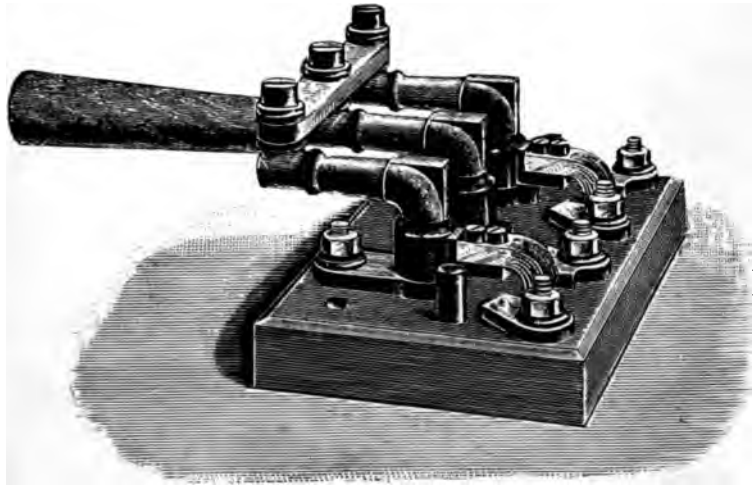


FIG. 16.

## 2. Cut-outs

These may be single or double pole. For experimental purposes the most suitable cut-outs are those in which the fuse wire is readily replaced, and which can also be used for fuses of different capacities

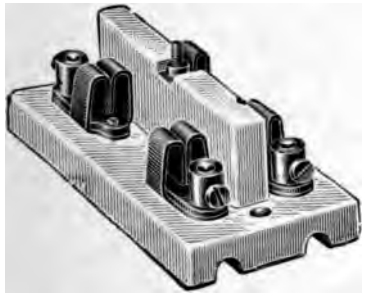


FIG. 17.

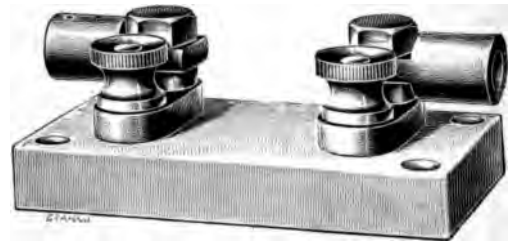


FIG. 18.

(see Fig. 17). For laboratory purposes cut-outs as shown in Fig. 18 suffice. They consist of a porcelain block with terminals, between which the fuse wire can be fastened. The cut-out may be enclosed

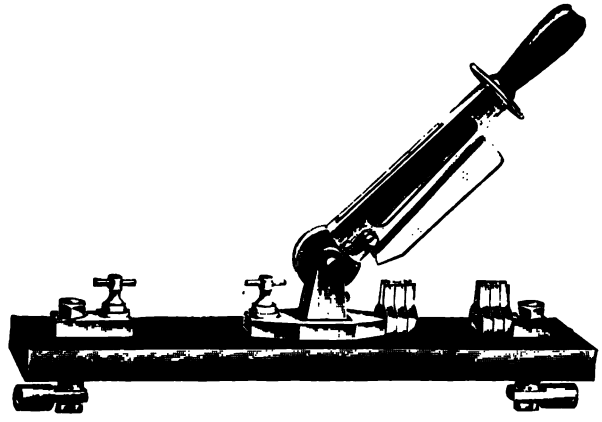


FIG. 19.

with a cover of non-inflammable material. The fuse wire usually consists of pure tin or a tin alloy; sometimes of lead. Copper wire should be used for small currents only. In using these cut-outs a number of experiments should be made to ascertain the fusing

currents of wires of different diameters. The distance between the terminals in the experiment must be the same as that in the cut-outs.

Switches and cut-outs are sometimes combined, as shown in Fig. 19. The combination has the advantage of economy of connections.

## 3. Wires and Cables

We may include under this heading—wires, cables, voltmeter leads, cable-shoes, and cable connectors.

The wires and cables should be cut ready into different lengths, the copper bared at the ends, and if possible tinned. A number of cables provided with universal cable-shoes is essential.

The insulation of the cables should be sufficient for 500 volts. A higher voltage is seldom used for C.C. machines. On the other hand, it is not advisable to use cables of lower insulation, as they are sometimes exposed to mechanical strains.

The current density allowable for temporary connections can be taken considerably higher than that of permanently laid cables. The following table indicates how far cables and wires may be loaded for short periods of time:—

| Sizes S.W.G. | Cross-sectional area in square inches. | Maximum current. |
|---|---|---|
| 18 | 0·0018 | 7 |
| 17 | 0·0024 | 9·5 |
| 15 | 0·004 | 16 |
| 7/20 | 0·0072 | 26 |
| 7/18 | 0·0128 | 37 |
| 7/14 | 0·0356 | 80 |

For connecting up voltmeters, special voltmeter cables are generally used. They consist of flexible cable of many fine strands. They are insulated with rubber, and tested up to 1000 volts.

Cable connectors, such as are frequently employed, are depicted in Fig. 20.

## 4. Starters and Regulators

For starting a continuous current motor a starter is required. It consists usually of a resistance that may be switched in series with the armature. If the stationary armature of a motor were switched

on directly to the mains, the resulting rush of current through the armature would be so excessive as to destroy the latter. By including some resistance in series with the armature this is diminished, and by making this resistance sufficiently large the starting current need not exceed the normal working current. The motor will then, corresponding to the small voltage across the armature, assume a certain speed, thus producing a back E.M.F. By gradually reducing the starting resistance the armature voltage will increase, till finally, when the resistance is cut out, the motor will reach its full speed. Hence, through the starting resistance a current flows for a brief period only—the starting of a motor requires, according to its size, about 20 to 60 seconds, seldom more. We may, therefore, use a high-current density in the resistance coils of the starter. On the other hand, if a resistance is to be used both for starting and regulating purposes,

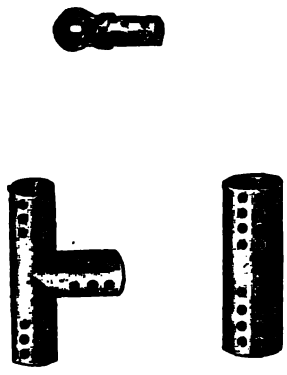


FIG. 20.

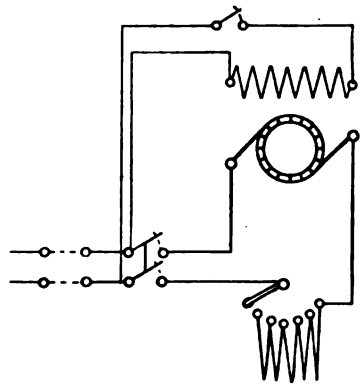


FIG. 21.

the full working current may pass through it for some considerable time, and the wire must be necessarily of a larger size. It is obvious, then, that a regulating resistance can always be used as a starter, but not *vice versâ*.

Before the armature circuit is closed, or at least simultaneously with it, the machine must be excited, *i.e.* the field circuit must be closed. With a series motor this condition is always fulfilled, as the armature and field are connected in series, thus receiving current simultaneously. In the case of the shunt motor it would be incorrect to connect the field across the armature terminals, for at the moment of starting the armature voltage is low, producing a small field current. The starting torque of the machine would consequently be practically zero. The field terminals must, therefore, be connected directly to the mains (see Fig. 21) and a switch provided in the

exciting circuit. As pointed out before, on starting, the field switch must be closed prior to the main switch; whereas, on stopping, the main circuit is broken first.

If, for starting, a simple rheostat only is used, it may be connected up as shown in Fig. 22. With this connection the whole resistance

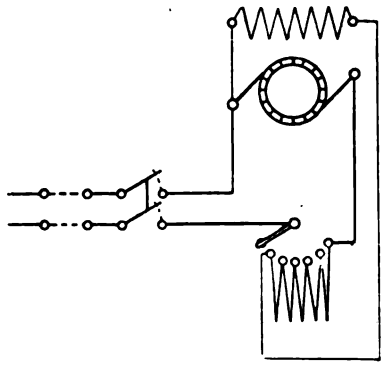


FIG. 22.

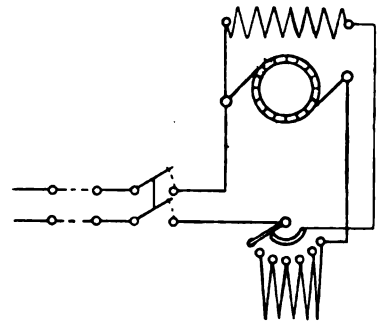


FIG. 23.

is permanently inserted in the field circuit, thus the exciting current, and hence the magnetic field, is somewhat weakened. As, however, the starting resistance is small compared with the field resistance, this makes hardly any difference in the speed.

Generally, special starting resistances for shunt motors are used, which are provided with a slip-ring for the field. In Fig. 23 we have such a starter. One end of the field is connected to the slip-ring, the other to an armature terminal. A lead from the second armature terminal to the last contact stop of the starter puts the former in circuit with the lever, which simultaneously slides on the shunt slip-ring. Thus, the field is, from the moment of starting, impressed with the full main voltage. For avoiding a spark on breaking, the connections shown in Fig. 24 are generally adopted.

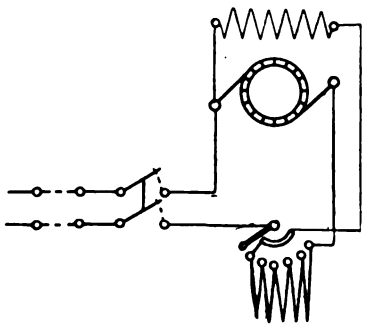


FIG. 24.

With all starters of this type the following rule should be observed: The motor terminal common to armature and field is to be connected to one main (say, the positive) and the second motor terminal to the starter terminal marked "Armature." The small terminal of the

starter must be connected with the free end of the field, and finally the remaining terminal of the starter with the other (negative) main.

The methods of construction of starting and regulating resistances are very numerous.* The most important types of resistances will be dealt with later on.

## 5. Shunt Regulators

Shunt regulators are used either for regulating the voltage of generators, or for the speed regulation of motors. With a dynamo running light, the shunt current, and hence the field, is generally larger than necessary to give the normal voltage. By inserting some resistance in the field circuit, the excitation is weakened until the voltage comes down to its normal value. With increasing load the field is weakened owing to armature reaction; thus the voltage of the generator will fall. To compensate this a part of the shunt resistance is cut out. The greater the load the larger will the armature reaction be, and the more shunt resistance must be cut out. Hence the shunt resistance must be made adjustable. The smaller the limits between which the voltage or the speed are allowed to vary, the larger must be the number of stops on the regulating resistance.

The construction of shunt regulators is similar to that of starters; the number of stops, however, is generally far greater with the former than with the latter. Although there may be a very large number of stops, a gradual regulation, as is necessary for certain experiments, is impossible. In these cases a resistance as shown in Fig. 25 (devised by Lord Kelvin) may be used. It consists of two metallic drums, one of which is covered with asbestos. The resistance wire is wound on the insulated drum, one end being connected with an insulated slip-ring, on which a brush slides; the other end goes to the second drum, to which it is fixed. A second brush slides directly on the uninsulated drum. By means of a lever and toothed wheel gearing the two drums can be turned simultaneously and in opposite directions. The resistance wire is wound from the insulated drum to the other. The resistance is the maximum so long as all the wire is on the insulated drum, but decreases as the wire is wound from the insulated to the bare drum. In the limiting position the resistance is nearly zero, as all the windings are short-circuited on the metal drum.

The resistances of shunt regulators, for regulating the pressure of a generator or the speed of a motor within small limits only, are, relatively to the field resistance, not very large. For instance, the resistance required to keep the terminal voltage of a dynamo constant between no load and full load would seldom be greater than 20 to 40 per

* See "Starters and Regulators," by R. Krause, translated by C. Kinzbrunner and N. West. Harper & Bros., London.

cent. of the field resistance. On the other hand, for varying the shunt current within wide limits, a relatively larger resistance is essential. With the regulator connected as in Fig. 26 (*i.e.* the usual way), an extremely large resistance would in many cases be required. In the case of the booster and certain experiments, as we shall see later on, this condition is requisite. As an example, in determining the internal characteristic of a machine—the normal exciting current of which is

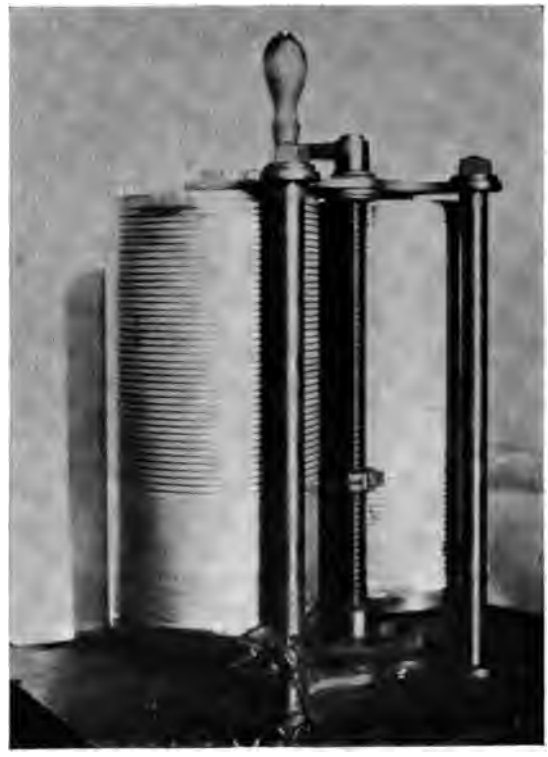


FIG. 25.

1 amp.—the minimum shunt current should be about 0·1 amp. An exciting voltage of 200 volts hence requires a shunt regulator of resistance 2000ω approximately.

To avoid the use of such large resistances the regulator may be connected up as shown in Fig. 27. By connecting even small resistances in this way the shunt current may be varied within the widest limits.

With this connection the field and the regulating resistance are in parallel. The voltage drop in the regulating resistance R is the exciting voltage. With the lever on the last contact the exciting voltage of the field is equal to the full pressure on the regulator R; the exciting current is then a maximum. By moving the lever to the left the exciting voltage is reduced, until finally, with the lever on

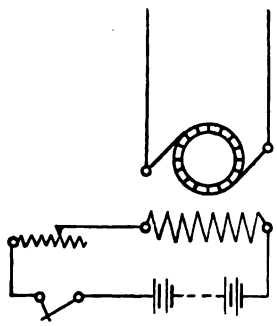


FIG. 26.

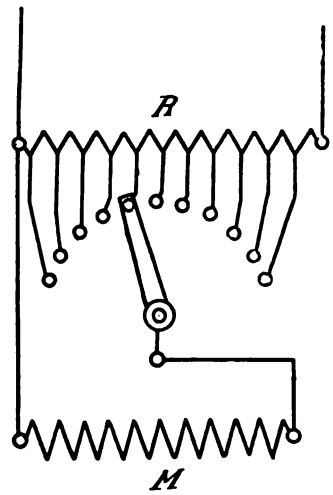



FIG. 27.

the first contact, the exciting voltage and consequently the field current are zero.

The $C^2R$ loss in the regulator with this connection is greater than with the usual connections; but this is for testing purposes, and therefore hardly of importance.*

As already mentioned, shunt regulators for speed regulation of motors must not have a contact on which the field circuit is broken.

The remarks in the following paragraph on the construction of regulators in general refer also to shunt regulators.

## 6. Loading Resistances and Methods of loading Generators and Motors

One of the most important tests for electric machines is that of permanent full load, during which the behaviour of the machine with regard to sparking, overheating, etc., has to be observed. During this

* See author's article in *The Electrical Engineer*, 1903 p. 561.

test the machine has to develop its full output; consequently arrangements have to be made to employ this output usefully, or to destroy it, *i.e.* to transform it into heat.

The most important methods of loading dynamos and motors will now be described.

In the case of motors the simplest way of loading is the brake method. The whole mechanical output is thereby transformed into heat. A complete description of some mechanical and magnetic brakes is given in Chapter IX. It must, however, be mentioned that with mechanical (friction) brakes a continual and constant load can hardly be obtained. For the purpose of permanently braking a motor, electro-magnetic brakes are used almost exclusively.

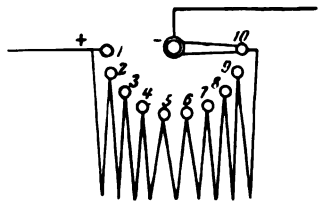


FIG. 28.

A method more generally employed for loading motors is the following: The motor is connected mechanically to another electric machine either by a coupling or by a belt (rope, etc.). This auxiliary machine is then used as a generator, and should be of about the same output as the motor under test. With regard to loading the auxiliary machine, the same methods may be adopted as for any other generator.

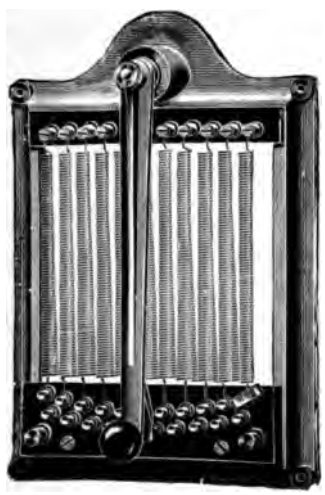


FIG. 29.

A dynamo may be loaded either by a suitable resistance or by connecting it to the supply mains.

The first is, if suitable resistances are available, doubtless the better and simpler of the two methods. Metal resistances are generally used, but in laboratories and test-rooms, glow lamps and liquid resistances are also employed.

The general type of a metal resistance is shown in Fig. 29 and the diagram of its connections in Fig. 28. The terminals of the dynamo are connected with the terminals of the rheostat marked + and − respectively. With the lever of the rheostat on contact 10, the whole of its resistance is in circuit; hence the load on the generator is a minimum. By turning the lever to contacts 9, 8, 7, etc., the resistance is gradually decreased, and thus the load of the dynamo

increased. With the lever on contact 1 all the resistance would be cut out and the dynamo short-circuited. In the rheostat shown in Fig. 29 the current passes through the centre bolt of the lever. With rheostats for large currents this is generally avoided, a slip-ring being provided from which the current is taken off. The diagram of such a resistance is shown in Fig. 30.

Since the contact plates of regulating resistances for larger currents are generally more costly than the resistance material itself, two rheostats in series are customarily used. One of these is a regulating resistance, whilst the other has no contacts. The size of the latter resistance has of course to be selected so that when the regulating resistance is cut out the load reaches the maximum required. Suppose a generator of 110 volts terminal pressure is to be loaded up to 10 amps., then of the two rheostats in series, the non-adjustable resistance (when hot) must be equal to $\frac{110}{10} = 11\omega$. In order that the current can be regulated from 1 to 10 amps., the adjustable rheostat must have a resistance of $\frac{110}{1} - 11 = 99\omega$.

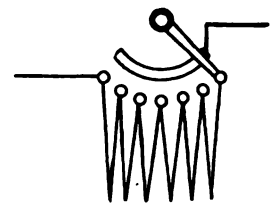


FIG. 30.

An essential requirement for a good rheostat is a small resistance variation with varying loads. The resistance of metals rises with increasing temperature (*i.e.* with increasing load). The percentage increase or decrease of the resistance of a material per 1° C. is called the "**Temperature coefficient**" of the material. It differs for various substances. The most suitable for rheostats are those metals whose temperature coefficients are the smallest. In the following table the temperature coefficients are given for various resistance materials:—

| | |
|---|---|
| Iron ... ... ... ... | 0·480 |
| Lead ... ... ... ... | 0·387 |
| Copper ... ... ... ... | 0·380 – 0·44 |
| Nickel ... ... ... ... | 0·365 |
| Platinum ... ... ... ... | 0·243 |
| Brass ... ... ... ... | 0·165 |
| Nickelin ... ... ... ... | 0·020 – 0·028 |
| German Silver ... ... ... | 0·036 |

In selecting a resistance material we must not only consider its temperature coefficient but also its specific carrying capacity—that is, the maximum current density permissible for a given rise of temperature. The specific carrying capacity depends on the sectional area and shape of the conductor. It decreases with increasing sectional area. The following tables give the values of the maximum current generally allowable for German silver and Nickelin wire (air cooled

and for permanent load). The specific carrying capacity is greater for strips than for wires, since with the former the ratio of cooling surface to cross-sectional area is larger than with circular wires, this ratio being greater the wider and thinner the strips are.

GERMAN SILVER.

| B.W.G. | Resistance of wire in ohms per yard. | Maximum current allowable. |
|---|---|---|
| 8 | 0·0170 | 60 |
| 12 | 0·0390 | 32 |
| 16 | 0·1095 | 15 |
| 19 | 0·2625 | 8 |
| 22 | 0·5910 | 5 |
| 25 | 1·1570 | 3 |

NICKELIN.

| B.W.G. | Resistance of wire in ohms per yard. | Maximum current allowable. |
|---|---|---|
| 8 | 0·0238 | 46 |
| 12 | 0·0547 | 25 |
| 16 | 0·1534 | 12 |
| 19 | 0·3675 | 7 |
| 22 | 0·8280 | 4 |
| 25 | 1·6200 | 2 |

In the above tables the maximum currents allowable and the approximate resistances per yard are tabulated. From these the total length of wire can be found for absorbing a given energy. As an example, a dynamo of 200 volts terminal pressure is to be loaded to an output of 10 amps. The total resistance required is $\frac{200}{10} = 20\omega$. Taking nickelin as the material, the size of the wire must be 16 B.W.G. Its resistance is about $0{\cdot}15\omega$ per yard; hence the requisite total length equals 133 yards.

The construction of starters and shunt regulators is generally similar to that of load rheostats. With the former the temperature coefficient is not of such importance as in the case of the latter. With starters, the resistance material is in use for but a brief period,

and, as pointed out before, can be loaded to a considerably higher value than that given in the table. In many cases the resistance material is cooled by immersion in a vessel filled with oil. By this means a slower and a uniform heating of the resistance is effected.

The resistance of starters is often selected so that on the first stop the initial momentary current is about equal to the normal working current. With large motors the supply authorities sometimes specify even a smaller starting current than the normal in order to avoid sudden variations of the supply voltage. Let $R_t$ be the total resistance of a motor (with a series motor $R_t = R_a + R_m$, with a shunt $R_t = R_a$), and let $C_n$ be the normal working current; then the starting resistance R is given by the equation—

$$R = \frac{E}{C_n} - R_t$$

where E = supply voltage.

Frequently starting and regulating resistances are combined. In this case the wires, etc., have to be designed for a permanent load.

Shunt regulators have to be always constructed for a permanent load. The amount of the resistance depends on the special purpose of the regulator, and is generally determined by experiment, which will be referred to later on.

With regard to the construction of the contact plates of starters,

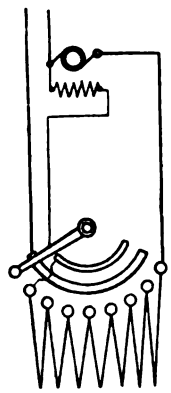


FIG. 31.

FIG. 32.

the current should pass (as with regulating resistances), not through the centre bolt of the lever, but through a separate slip-ring. Hence larger starters are generally provided with two slip-rings. The diagram of such a starter is shown in Fig. 31, and one of the most usual types illustrated in Fig. 32.

Many starters are provided with a no-voltage release and a maximum cut-out, the latter frequently designed to act at 50 per

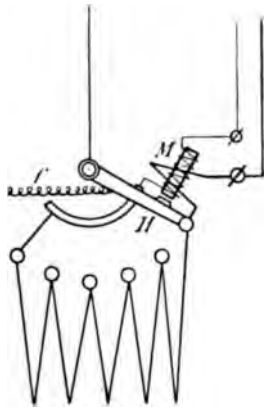



FIG. 33.

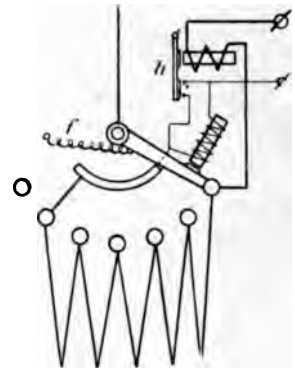



FIG. 34.

cent. overload. Figs. 33 and 34 illustrate two different principles of such starters. In Fig. 33 the magnet M is excited by a thin wire

FIG. 35.

FIG. 36.

coil in the field circuit of the motor immediately the latter is started. The lever H is kept in its utmost position as long as M is magnetized

above a certain minimum value. Below this the magnetism of M becomes so weak that the spring *f* (or a weight) pulls the lever to its off-position, and thus the motor stops. The magnet M is provided also with a few series turns (*i.e.* in series with the armature of the motor), which oppose the thin or shunt windings. At normal load the shunt coil amply overcomes the series turns, but at overload the latter preponderates. With overload M loses its magnetism, and the lever is drawn to the off position. With the construction as shown in Fig. 34 at overload, the lever *h* is attracted, thereby short-circuiting the coil M. Fig. 35 shows a starter with no-voltage release and overload cut-out with connections, as in Fig. 34.

The construction of contact plates for shunt regulators differs but little from that of starters. A complete shunt regulator is depicted in Fig. 36. With machines for higher voltages, and with separate excitation, the shunt circuit should not be broken by the shunt regulator, but by a special field switch. In breaking a circuit of high self-induction, as the field windings for high voltages, a high E.M.F. of self-induction arises which may sometimes break down the insulation. With these field switches a "buffer" circuit is closed at the moment of breaking the field, through which the current produced by the E.M.F. of self-induction can flow without doing any damage. Such a switch is illustrated in Fig. 37.

FIG. 37.

Glow lamp resistances for loading dynamos are combined as lamp batteries. They are very cheap and handy. Their main disadvantage, however, is that they can only be used for certain voltages. It is best to use parallel connected sets of 130 and 250 volt lamps respectively. By switching such sets in series they can be used for voltages up to 420-440 volts.

A liquid resistance consists of a tank filled with dilute acid or alkali, into which two metal plates dip. The metal plates serve as electrodes, the liquid as the resistance material. The advantages of liquid resistances are cheapness and the small space required; their disadvantages—great difficulty of fine adjustment, and inconstancy of resistance owing to electrolysis. With the more elaborate constructions these disadvantages are mostly avoided, but then their main advantage, cheapness, is lost. For loading small machines, liquid resistances are seldom used in laboratories and test-rooms. For testing large machines, however, especially if the test

has to be made after the erection of the machine, they are sometimes the only means available.

Recently liquid resistances have been used for starters. They are in this case provided with metallic contacts for short-circuiting the liquid.

With all the methods described above, the energy produced in the dynamo has been wasted; these methods are, therefore, anything but economical. An economical way of loading a dynamo is to connect it to the supply mains, *i.e.* to work in parallel with the station generator.

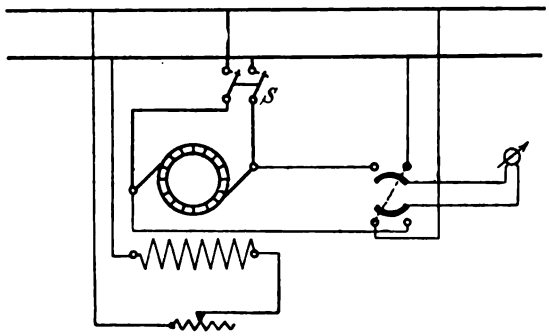



FIG. 38.

If the voltage of the dynamo to be loaded is equal to the supply voltage, then the following is a simple method. The dynamo is run at normal speed, and its terminal voltage regulated until it equals the supply voltage. In order to verify this, it is best to use a voltmeter switch (see Fig. 38). If both voltages are equal, the switch S is then closed. The load of the dynamo will at first be but very small. By increasing the field current, the dynamo load will correspondingly increase, and *vice versâ*. If after reducing the dynamo load to zero the shunt current is weakened further, the mains will supply current to the machine, and the latter runs as a motor. Its direction of rotation of course remains the same as before.

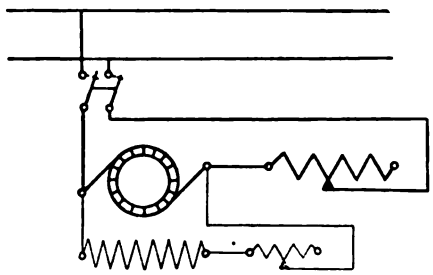


FIG. 39.

If the terminal voltage of the dynamo is greater than that of the supply mains, the dynamo may work on both the network and resistances simultaneously. A diagram of connections as required then is shown in Fig. 39. With these connections part of the dynamo voltage is absorbed by the resistance.

An arrangement similar to that shown in Fig. 38 is frequently

used for loading and testing the efficiency of two machines of equal type and output (Hopkinson's method). The method will be referred to subsequently.

In some cases the energy available is insufficient to load a big machine. To determine the overheating at a particular load, the armature of such a machine should be short-circuited by an ammeter and run at full speed. By weakly exciting the field, any current can be produced in the armature. The behaviour of the machine with regard to sparking with various armature currents and brush positions can in this manner be studied. To obtain a sufficiently small exciting current the shunt resistance may be connected up as shown in Fig. 27.

The overheating of the field windings is determined with the full exciting voltage for several hours, the armature being stationary.

## 7. Measuring Instruments

The value of a machine test depends largely on the judicious selection and the proper use of the measuring instruments employed. One must therefore be thoroughly acquainted with the use of those instruments necessary in subsequent experiments.

Owing to the great extent of this subject it is impossible to deal fully with it in this treatise, but a short description will be given of instruments generally employed in the testing of C.C. machinery.

The following types of instruments may be classed according to the effects of the electric current:—

1. Electro-chemical.
2. Electro-magnetic.
3. Electro-dynamic.
4. Electro-caloric.
5. Electro-static.

### 1. Electro-chemical Instruments.

These instruments (called voltameters) are hardly ever used for testing machinery, but frequently for calibrating other instruments. They will therefore not be dealt with.

### 2. Electro-magnetic Instruments.

To this class the following types belong, the functions of which depend upon—

A. The action of a stationary coil (through which the current to be measured passes) on a movable magnet; or

B. The attraction of a soft iron core by a coil traversed by the current; or

C. The action of a fixed magnet on a movable coil carrying the current to be measured.

*Type A.*

The various needle galvanometers belong to this type. Except for measuring insulation resistance these instruments are not used for practical measurements on C.C. machines. The objections are they are not portable, and (a few of special construction excepted), are affected by neighbouring currents and fields.

*Type B.*

This includes the majority of switchboard instruments. The current flowing through a coil attracts a piece of soft iron, the latter transferring its motion to a pointer. The opposing force is in most cases gravity, or the tension of a spring, and in some permanent magnets are used. Since the attraction or repulsion of the core is not proportional to the distance between the core and the centre of the coil, the scale of these instruments is not uniformly divided. The force which the coil exerts on the core is but very small, so that even with large overloads the instruments are not destroyed.

The advantages of these instruments are their simplicity and cheapness.

On the other hand, these instruments have great disadvantages

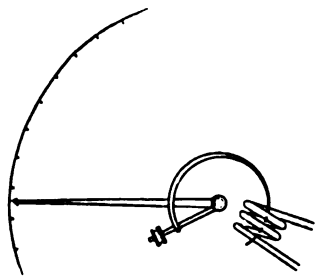


FIG. 40.

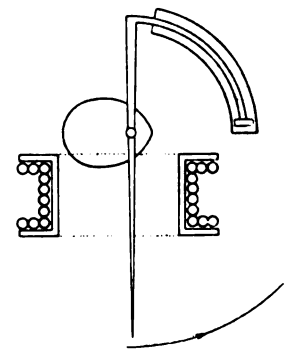


FIG. 41.

also. They are influenced by external magnetic fields (and currents), and their reading varies with the time they are in circuit. Owing to hysteresis in the iron core, the deflection is not the same with increasing as with a decreasing current.

Some of the most important instruments of this type are shown in Figs. 40–43. The instrument in Fig. 40 (made by Messrs. Siemens & Halske) possesses a circular piece of soft iron, which is drawn within the coil by the current. The adjustment of the zero is made by means of a small weight. One of the best instruments of this type, also by Messrs. Siemens & Halske, is shown in Fig. 41. The movement of the pointer is damped by a disc moving in a tube.

Another type is illustrated in Fig. 42. In the interior of the coil are arranged a fixed curved piece of iron A and a movable flat piece N attached to a pointer. With the passage of current through the coil

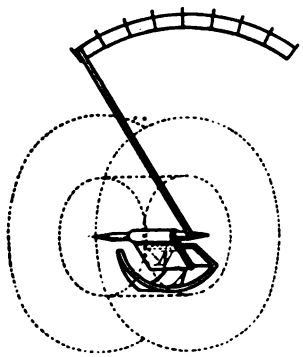


FIG. 42.

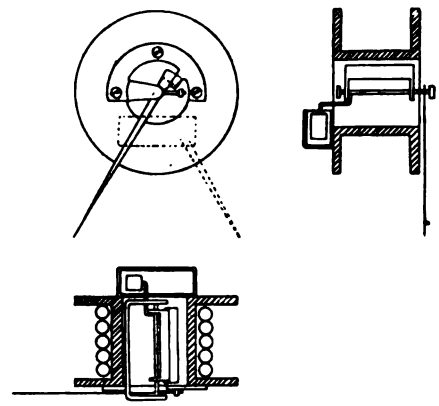


FIG. 43.

A and N become magnetized, and repel each other. An instrument depending on a similar principle is shown in Fig. 43, with the addition of an oil-damping arrangement.

Soft-iron instruments must not be placed near machines nor cables carrying large currents. If the instruments are left in circuit for some time, readings should not be taken before 15 to 20 minutes after switching in. They will necessitate frequent calibration and the mean be taken for ascending and descending currents.

*Type C.*

These instruments consist essentially of a powerful horse-shoe shaped magnet with cylindrically bored poles, in the interior of which an iron cylinder is fixed. The air gaps between the iron cylinder and the poles are small and uniform throughout. In these air gaps a coil, consisting of very fine wire (through which the measuring current flows), moves about its axis. In the position of rest the plane of the coil is at right angles to the direction of the lines of force

of the permanent magnet. A current flowing through the coil creates a magnetic field at right angles to that of the lines due to the permanent magnet. Owing to the tendency of the two fields to assume a parallel direction the coil is deflected. The angle of deflection is within certain limits proportional to the strength of the current. The controlling force with galvanometers of this type is the torsion of the suspension wire, but with portable instruments the torsion of two springs, through which at the same time the current enters and leaves the coil (see Fig. 44).

The commercial instruments of this type (as shown in Fig. 45) belong to the best and most used precision instruments. The accuracy

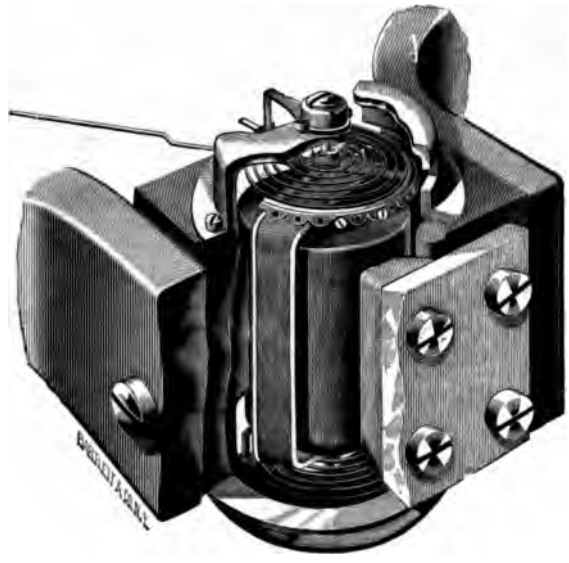


FIG. 44.

of the type is very high, being about 0·2–0·5 per cent. This kind was first made by the Weston Company, and now nearly every firm produces instruments of this type. Figs. 45 and 46 show two well-known types of the Weston instruments. The reading on laboratory instruments of the Weston pattern is considerably facilitated by the transversal scale illustrated in Fig. 47. With proper usage the constant of these instruments will vary but very little for a long time, so that an occasional checking is only necessary. A small current consumption adds a further advantage to them.

The Deprez instruments are frequently combined with a number of shunts and multipliers and employed as universal instruments.

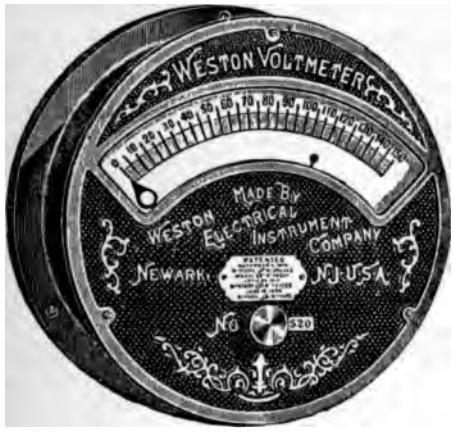



FIG. 45.

FIG. 46.

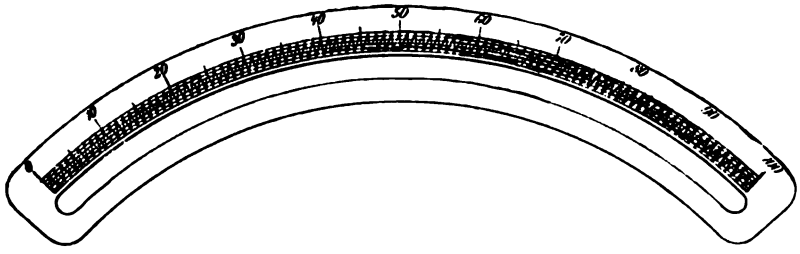


FIG. 47.

FIG. 48.

Such a set is illustrated in Fig. 48. It may be used as a milli-volt-ammeter, as a voltmeter up to 600 volts, and with separate shunts as ammeter up to 600 amps. These instruments, though very convenient, must be used with great care.

### 3. Electro-dynamic Instruments.

Electro-dynamometers are based on the mutual action of currents flowing in two coils. The oldest typical instrument (made by Siemens & Halske) is shown in Fig. 49. It consists of a fixed and a movable coil, which in the normal position are at right angles to each other. Both coils are connected in series. When a current traverses the coils the fields produced are at right angles, and hence the coils tend to take up a parallel position. The movable coil with an attached

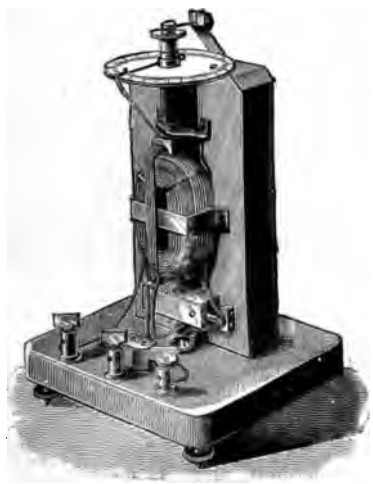


Fig. 49.

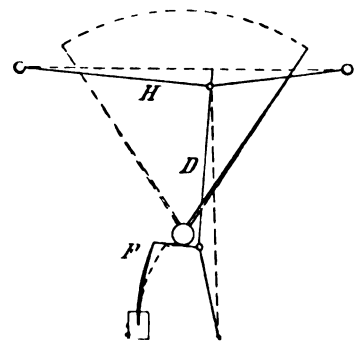



Fig. 50.

pointer will be deflected. By turning a milled head a torsion spring connected with the movable coil is stretched until the latter (with its pointer) is brought back to its zero or normal position. The milled head is provided with another pointer, which indicates on a scale beneath it the angle of torsion necessary to bring the coil to zero. This angle is a measure of the current strength.

With a careful and correct adjustment the readings of these instruments are very accurate. For practical measurements, however, they cannot be used, the adjustment being troublesome (momentary variations of the current cannot be observed at all), and they are difficult to carry about.

Direct-reading electro-dynamic instruments have recently been

constructed, in which, as the name implies, the deflection of the movable coil is measured directly (*i.e.* without bringing it to its zero position). Electro-dynamometers are used for alternating current rather than continuous current testing.

### 4. Electro-caloric Instruments.

In this class of instruments only the hot-wire instruments, the principle of which is shown in Fig. 50, are of practical importance.

Fastened to the wire H (which carries the current) is a second wire D, to which a third wire, wound on a pulley and ending on the spring F, is attached. On the axis of the pulley a pointer is fixed. With the passage of current, the wire H expands, and the sag is taken up by the spring, as shown by the full lines in the sketch. The pulley turns, and the pointer is deflected to the left. The deflection is not proportional to the current strength, hence the scale is not equally divided. As the length of the wire H varies with the temperature of the air, with a consequent alteration of the zero position of the pointer, these instruments must be provided with a zero adjustment. If current passes through the wire for some time, the constant of the instrument is altered.

Notwithstanding their advantages these instruments are not very often employed for C.C. measurements. Their chief domain is in alternating current measurements.

### 5. Electro-static Instruments.

The principle of their action is based on the force arising from two points of different potentials. For the measurements in connection with C.C. machines, these instruments are seldom used.

The following table shows approximately the mean accuracy for the various types of instruments:—

| | | | |
|---|---|---|---|
| Deprez instruments ... ... | about | $\frac{1}{4}$ | per cent. |
| Electro-dynamometers ... ... | " | $\frac{1}{2}$–$\frac{3}{4}$ | " |
| Hot-wire instruments ... ... | " | 1–2 | " |
| Soft-iron instruments, a maximum of | about | 2 | " |

## Sources of E.M.F.

For testing direct current machinery both accumulators and dynamos are used. For some experiments accumulators are indispensable, and they are specially suitable for the separate excitation of machines.

Accumulators provided with cell switches and a small regulating resistance (see Fig. 51) have the advantage of giving a pressure variation within very wide limits. Moreover, their pressure remains

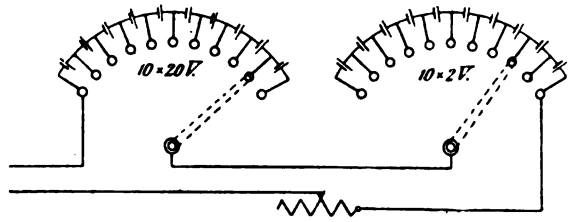



FIG. 51.

fairly constant during a test, provided that the capacity of the battery is large compared with the energy required.

If supply mains be used for a test, it is very essential that the pressure be as steady as possible. In laboratories and test-rooms there should be a dynamo with separate excitation, and its voltage variable within wide limits.

The pressures most frequently used for testing C.C. machinery are 110–130, 220–250, 440–450 volts.

# CHAPTER II

# RESISTANCE MEASUREMENTS

For the determination of the overheating and the ohmic losses in the armature and field of C.C. machines, their respective resistances must essentially be known. The following is a classification of the resistances of a C.C. machine :—

1. Armature Resistance.
2. Contact Resistance (between brushes and commutator).
3. Brush Resistance.
4. Resistances of Cables connecting the brush-holder pins with the main terminals.
5. Total Armature Resistance.
6. Field Resistance.

Of the above, (4) is generally extremely small, so that it need not be measured separately. The same applies to (3) if the material of the brushes is metal.

The measurement of (1) and (2) is by no means simple. The exact measurement of these resistances offers sometimes great difficulties, and requires an accurate knowledge of all circumstances that may possibly influence the measurement. We shall treat (1) and (2) very fully, owing to their great importance.

## Armature Resistance

The armature resistance must be known to determine the overheating and the ohmic drop of an armature. In a later chapter we shall have an opportunity of dealing with the overheating.

According to the value of resistance one of the following methods is adopted :—

(*a*) Indirect method.
(*b*) Method of comparison of deflections.
(*c*) Thomson's double bridge method.

The first is by far the simplest and most convenient, and almost exclusively used in test-rooms. It is, however, not reliable for very small resistances, and one of the other methods is then resorted to.

In any of the three methods we can either have all the brushes resting on the commutator, in which case the resistance is measured between any two segments touching adjacent brushes of opposite polarity, or the current may be led to two particular commutator segments only, between which the resistance is measured. In the first case the result will generally be inaccurate, owing to the variable contact resistance of the brushes causing an unequal distribution of current in the armature sections with parallel and series-parallel windings. In the second case the knowledge of the type of armature winding and winding pitch is essential. With the help of the following table * the particular commutator segments by which the winding is divided into two equal parts can be ascertained. The resistance between these commutator bars is a fourth part of the resistance of all the sections in series. With armatures having an *odd* number of coils the resistance $r'$ as measured differs a little from the true resistance $r$.

$$r = \frac{r's^2}{s^2 - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $s$ = number of conductors.

From the true resistance $r$, which, as stated above, is equal to the fourth part of the resistance of all the coils in series, the armature resistance $r_a$ is deduced.

$$r_a = \frac{r}{a^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where $2a$ = number of armature sections in parallel.

The following table gives the number ($x$) of commutator segments between which the resistance $r'$ is to be measured for the different types of windings :—

* See Wettler, *Electrotechnische Zeitschrift*, 1902, p. 3.

VALUES OF $x$.

| Type of winding. | No. of commutator segments per armature winding. $\frac{K}{n}$ | Commutator pitch. | $x$ |
|---|---|---|---|
| Series, parallel, and series-parallel. | even | even or odd | $\frac{K}{2}$ |
| Series and series-parallel. | odd | even | $K - \frac{y_1 + y_2}{4}$ |
| | | odd | $\frac{K}{2} - \frac{y_1 + y_2}{4}$ |
| Parallel. | odd | even or odd | $\frac{K - n}{2}$ |

K = number of commutator segments.
$y_1$ and $y_2$ = front and back pitch respectively.
$n$ = number of independent armature windings (generally = 1)

It is seen from this table that for all windings with an even number of commutator bars, and all parallel windings, the resistance is to be measured between diametrically opposite commutator bars.

The application of the above formulæ is illustrated by the following examples :—

EXAMPLE I. (*see* Fig. 52).

*Parallel Winding.*

No. of conductors, $s = 32$
Pairs of poles, $p = 3$
No. of armature sections, $2a = 6$
Front pitch, $y_1 = 7$
Back pitch, $y_2 = 5$
No. of commutator bars, $K = 16$

In the table of values of $x$ we have for a parallel winding and an even number of commutator segments—

$$x = \frac{K}{2} = \frac{16}{2} = 8$$

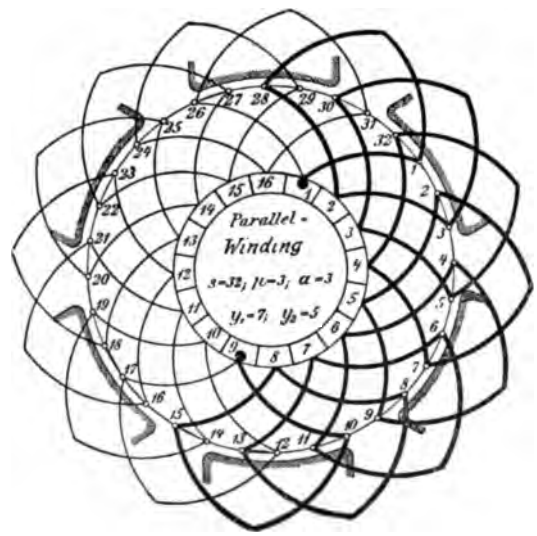



FIG. 52.

Thus the resistance is to be measured between two commutator bars distant by 8, viz. between 1 and 9, 2 and 10, etc.

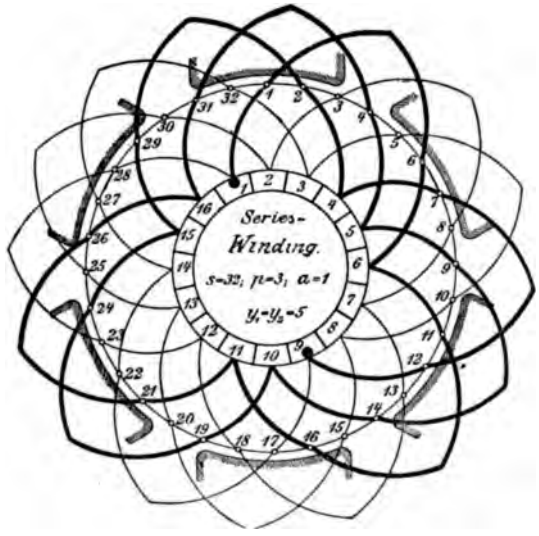



FIG. 53.

EXAMPLE II. (*see* Fig. 53).

*Series Winding.*

$s = 32$
$p = 3$
$a = 1$
$y_1 = y_2 = 5$
$K = 16$

$$x = {}_2 = \mathbf{8}$$

The resistance is measured as in Example I., between bars 1 and 9, etc.

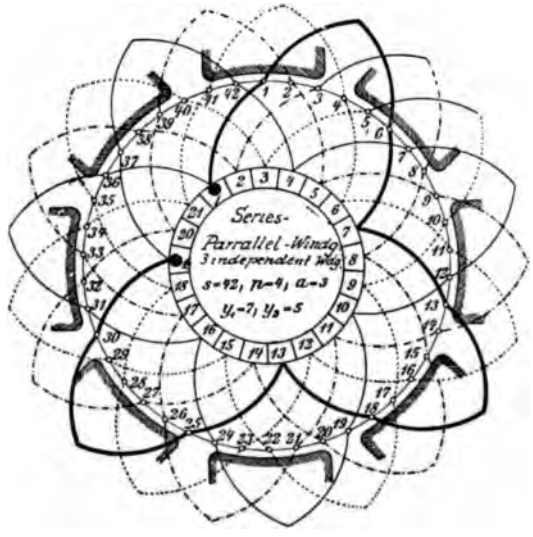



FIG. 54.

EXAMPLE III. (*see* Fig. 54).

*Series-parallel Winding (three independent windings).*

$s = 42$
$p = 4$
$a = 3$
$y_1 = 7$
$y_2 = 5$
$n = 3$
$\frac{K}{n} = 7$

Commutator pitch *even.*

$$x = K - \frac{y_1 + y_2}{4}$$

$$= 21 - \frac{12}{4} = 18$$

The resistance in this case requires measuring between segments 1 and 19.

## Experiment No. I

*Measurement of the Armature Resistance.*

It has been stated that for measuring armature resistances in test-rooms the indirect method is most frequently employed. By this method resistances ranging from about 0·05–0·10$\omega$ can be measured with sufficient accuracy. Smaller armature resistances are, whenever possible, measured by the comparison of deflection method, and for still lower resistances by Thomson's Double Bridge method.

We can only take a brief survey of the three methods, as acquaintance with them is assumed.

### (*a*) The Indirect Method.

If a current, $c$, of a known strength is passed through a conductor of unknown resistance $r$, and the measured pressure difference of its ends be E, then by Ohm's Law—

$$r = \frac{E}{c}$$

Diagram of Connections.

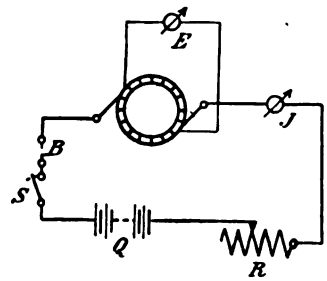



Fig. 55.

*Instruments and Apparatus required.*

J = Ammeter, reading 50 per cent. of normal armature current.
E = Voltmeter according to output and voltage of machine, reading about 15 per cent. of armature voltage.
R = Regulating resistance.
S = Main switch.
Q = Source of E.M.F., preferably accumulator cells of sufficient capacity.
B = Fuse.

*Experiment.*—After closing the switch S, regulate the current by means of R to about a quarter or one-third of the normal armature current. The ammeter and voltmeter should be observed simultaneously and recorded. Repeat with various currents for, say, one-third and one-half normal, then—

$$r = \frac{E}{c}$$

For exact measurements the current flowing through the voltmeter must be taken into account, thus—

$$r = \frac{E}{c - \frac{E}{r_v}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where $r_v$ = voltmeter resistance.

The arithmetical mean of the results for different currents is taken.

The commutator segments between which the resistance is to be measured are deduced by the rules already stated.

With this, as with all measurements of resistance, the temperature of the winding must be considered. The resistance of the winding varies with temperature, hence the latter must simultaneously be obtained. The temperature of the winding will be practically that of the surrounding air if observations are quickly conducted and the current used not greater than one-half normal.

### Example Ia.

*Measurement of Armature Resistance (Indirect Method).*

Armature (machine), No. 2640, 440 volts, 20 amps.
Instruments used—Vulcan Volt-ammeter.
Measured when cold. Air temperature, 17° C.

Record of Results.

| Amps. | Volts. | Resistance. |
|---|---|---|
| 5·0 | 4·2 | 0·84ω |
| 7·5 | 6·37 | 0·85ω |
| 10 0 | 8·6 | 0·86ω |

Average ... ... $\frac{2{\cdot}55}{3} = \mathbf{0{\cdot}85\omega}$

### (*b*) Comparison of Deflection Method.

If a current, $c$, of unknown strength flows through two conductors (connected in series) of resistances $r_1$ and $r_2$ respectively, the voltage drop across each of these conductors will be proportional to the respective resistances.

Since $e_1 = cr_1$

$$e_2 = cr_2$$
$$e_1 : e_2 = r_1 : r_2$$

If $r_1$ is known, then $r_2$ is determined from the equation—

$$r_2 = r_1 \cdot \frac{e_2}{e_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

For measuring armature resistance by this method the knowledge of the relative voltage drop in the armature and standard resistance connected in series are thus only necessary.

Diagram of Connections.

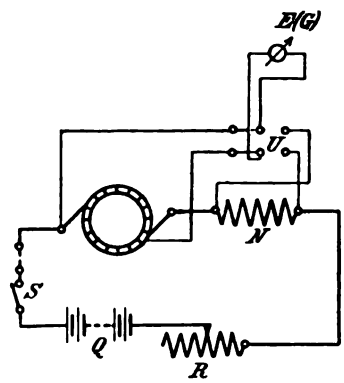



Fig. 56.

*Instruments and Apparatus required.*

N = Standard resistance of the same order as the armature.
R = Regulating resistance.
E = Sensitive low reading voltmeter (millivoltmeter), or
G = Galvanometer.
S = Main switch.
U = Two-way double-pole switch.
Q = Source of E.M.F. (two or three accumulators).

*Experiment.*—Close switch S, and put lever of U to the right, and regulate the current by means of R to obtain a sufficiently large deflection; throw the lever of U to the left, and if the deflection is now too great, reduce the current by means of the regulating resistance R. If the armature and standard resistance are about equal, the two deflections will (with the same current) be about equal too. After these preparations make the experiment with the lever in one position, note deflection, then throw over the lever, and observe deflection again. In the event of the battery available for this experiment being small, the lever should again be turned to the original position, and another reading obtained. In this case the mean of the first and last readings is taken for the particular position of the lever of U. Let $a_1$, $a_2$, and $a_3$ be the three deflections, $x$ the armature resistance, and N the standard, then—

$$x = \mathrm{N}\frac{a_2}{\frac{1}{2}(a_1 + a_3)}$$

the deflection $a_2$ corresponding to $x$.

### Example Ib.

*Measurement of Armature Resistance (by Comparison of Deflection Method).*

Armature (machine), No. 27436, 100 volts, 350 amps.
Instruments used—Weston Millivoltmeter, No. 1926.
Measured when cold. Air temperature, 17·5° C.

| Standard resistance N. | Deflections. | | | | Armature resistance $x$ | Remarks. |
|---|---|---|---|---|---|---|
| | Standard resistance. | | | Armature. | | |
| | $a_1$ | $a_3$ | Mean. | $a_2$ | | |
| 0·01ω | 14° | 14° | 14° | 18·2° | 0·013ω | I. |
| 0·01ω | 22° | 22·5° | 22·25° | 28·8° | 0·129ω | II. Current increased. |
| | | | | | $x = 0{\cdot}01295\omega$ | |

### (c) Thomson's Double Bridge Method.

For measuring very small resistances (0·01$\omega$ and less) neither of the methods already described can be expected to give a great accuracy. The Thomson's Double Bridge method is then resorted to. For the theory and description of this instrument the reader is referred to any of the special works on this subject.

Diagram of Connections.

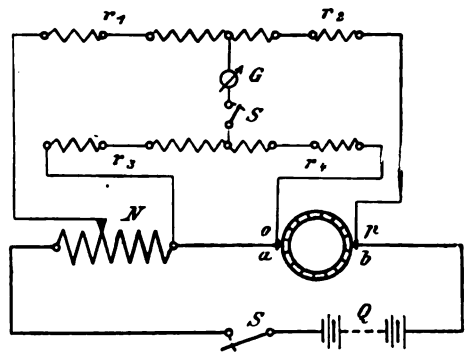



Fig. 57.

*Instruments and Apparatus required.*

A complete bridge consisting of four groups of resistances—$r_1$, $r_2$, $r_3$, and $r_4$, of which $r_1 = r_3$ and $r_2 = r_4$.
An adjustable standard resistance.
A very sensitive galvanometer.
Main switch, S.
Galvanometer key.
Small battery, Q.

*Experiment.*—Connect the ends $a$ and $b$ of the main circuit with the commutator segments of the armature, and ensure that the contact is good. The wires $o$ and $p$ from the bridge are connected exactly to the points between which the resistance is to be measured, *i.e.* on the commutator bars themselves. Close S so that current flows through the standard resistance and the armature. By suitably varying the resistances $r_1$, $r_2$, $r_3$, and $r_4$, a state of balance is produced in the branches, when the galvanometer indicates no deflection on depression of the galvanometer key. Note that $r_1$ must always $= r_3$ and $r_2 = r_4$.

If no current passes through the galvanometer, the armature resistance—

$$x = N\frac{r_2}{r_1} = N\frac{r_4}{r_3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

In this method neither variations of the main current nor resistance of the galvanometer have any influence on the measurement. It is therefore possible to have the galvanometer itself fixed up in a special room, whilst the armature may remain in the test-room.

EXAMPLE IC.

*Measurement of Armature Resistance (by Thomson's Double Bridge Method).*

Armature (machine), No. 27436, 100 volts, 350 amps.
Instruments used—Thomson's Bridge.
Measured when cold. Air temperature, 17·5° C.

RECORD OF RESULTS.

Standard resistance = $0{\cdot}01\omega$
$r_1 = 130\omega$
$r_2 = 100\omega$
$r_3 = 130\omega$
$r_4 = 100\omega$
Armature resistance = $0{\cdot}01 \times \frac{130}{100} = \mathbf{0{\cdot}013}\omega$.

## Contact Resistance

The contact resistance will be essential in the determination of the individual losses of C.C. machines. This resistance is, generally speaking, with copper brushes, and with a perfect contact between commutator and brush very small compared with the armature resistance. With carbon brushes, however (which are now extensively used), and especially if the contact on the commutator surface is imperfect, the contact resistance sometimes forms a considerable part of the total armature resistance. In the case of small machines the contact resistance is often not much smaller than the armature resistance.

The following factors determine chiefly the contact resistance:—

(*a*) Material of brushes and commutator.
(*b*) Pressure of brush on commutator.
(*c*) Current density at the area of contact.

(*d*) Peripheral speed of the commutator.
(*e*) The quality of commutator surface (whether smooth or rough).

All these factors have naturally to be considered in the measurement.

## Experiment No. II

*Measurement of the Contact Resistance between Brushes and Commutator.*

DIAGRAM OF CONNECTIONS.

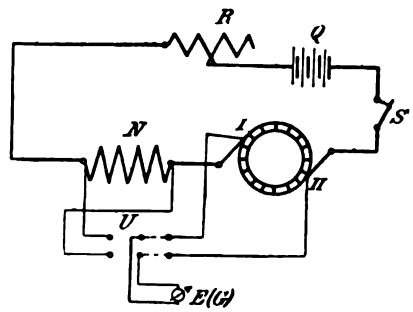



FIG. 58.

*Instruments and Apparatus required.*

N = Adjustable standard resistance.
R = Regulating resistance.
E = Millivoltmeter (with an equally divided scale).
S = Switch.
U = Two-way double-pole switch.
Q = Battery.

*Experiment.*—All but two brushes (on separate holder-pins) should be taken off the commutator. In this way the contact resistance, which in itself is but small, will be increased and can thus be easier and more accurately measured. Any of the three methods for measurement of resistance previously described may be adopted. In the majority of cases, however, the contact resistance exceeds $0{\cdot}001\omega$, so that it is unnecessary to use Thomson's Double Bridge method. The resistance is measured between I. and II. (see Fig. 58). The two wires must be kept as near to the contact surfaces as

possible, otherwise part of the brush resistance will be included. The current entering brush I. passes through the armature winding and leaves by brush II. With this arrangement not only the contact resistance of the two brushes, but the armature resistance, would also enter into the measurement. To eliminate the latter, the armature winding must be short-circuited. This is best accomplished by winding a copper wire of medium thickness several times round the commutator.

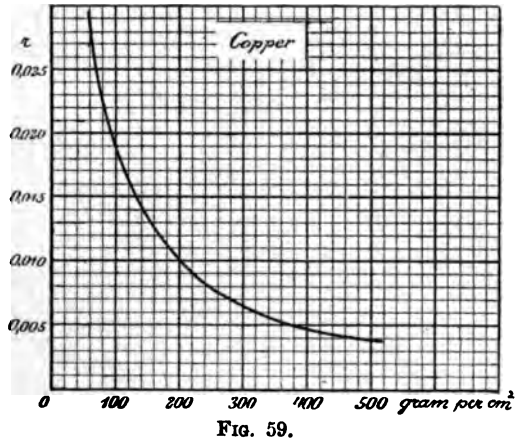



FIG. 59.

Care should be taken that the bearing pressure of the brushes on the commutator is the same as during normal working. The contact resistance varies with the pressure; it decreases with increasing pressure, and *vice versâ*. The pressure should be neither too small nor too great—to avoid in the first case an excessive ohmic resistance (and ohmic loss), and in the latter case a large mechanical (friction) loss. In Figs. 59 and 60 the two curves shown represent the contact resistance as a function of the specific pressure for carbon and copper brushes respectively. In both cases the commutator segments are hard drawn copper.

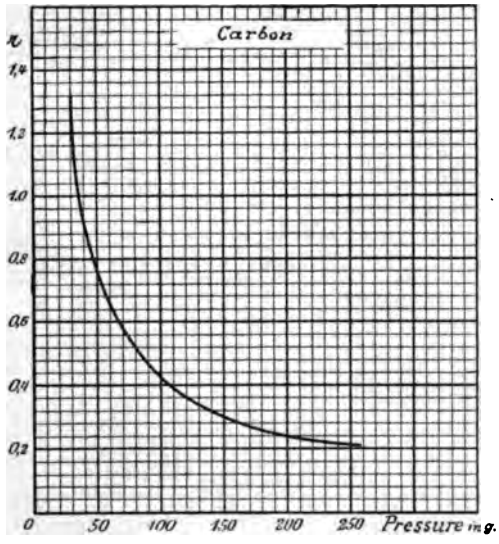



FIG. 60.

The current density on the contact surface has also a decided influence on the contact resistance, such, that the latter decreases

with increasing current density. In Figs. 61 and 62 the contact resistance is plotted against the current density for carbon and copper brushes respectively. We therefore see the necessity of measuring the contact resistance with the normal working current (for the brush). Let $c$ be the normal working current of the machine, and $m$ the total number of brushes on the machine, then, with the arrangement described above (viz. the two brushes), the test current $c_1$ for normal conditions should be—

$$c_1 = \frac{2c}{m}$$

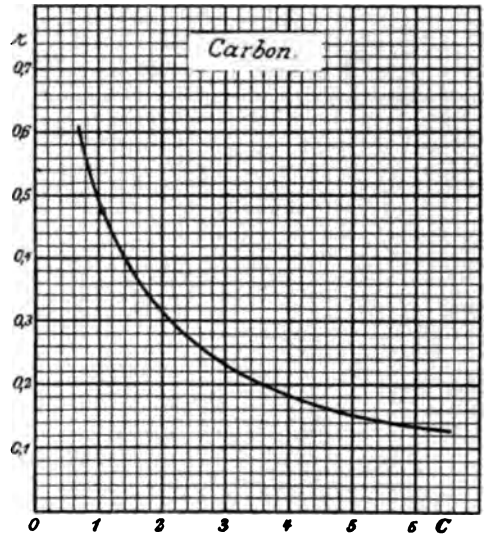



FIG. 61.

If the contact resistance of a brush be observed in the two cases, firstly, the armature at rest, and secondly, rotating, we shall find that in the latter case the contact resistance has increased. Fig. 63 shows clearly the increase in the contact resistance with peripheral speed of the commutator. From a great number of experiments Dettmar * has found that the contact resistance increases up to a peripheral speed of the commutator of 2 metres per second. The resistance remains practically constant beyond this speed. A speed of 2 metres per second will therefore suffice during measurement of the contact resistance, and under no circumstance should the commutator be at rest whilst the measurement is taken.

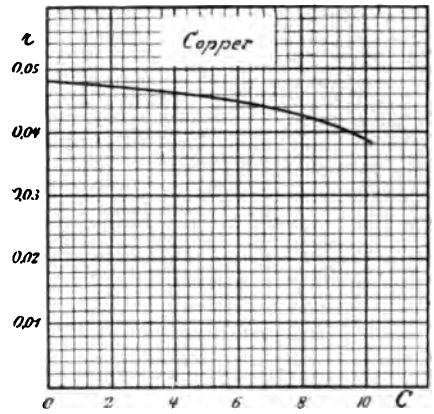



FIG. 62.

* *Electrotechnische Zeitschrift*, 1900, p. 429.

With regard to the surface of the commutator, it is obvious that the contact resistance is smaller the smoother and cleaner the surface is. The measurement of the contact resistance should be made after the machine has been working for several hours with full load, as the condition of the commutator surface will then be the same as during normal working.

All the above points in measurement of contact resistance may be summarized as follows :—

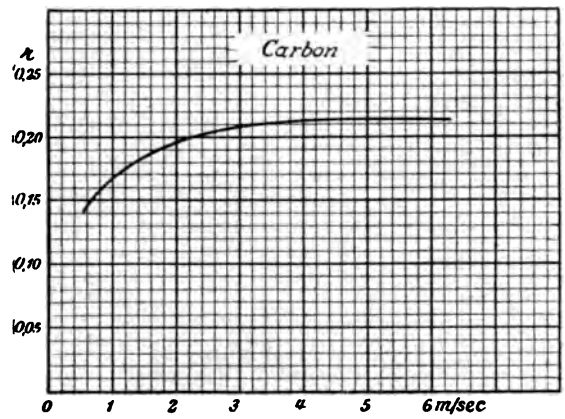



FIG. 63.

(1) The two brushes between which the resistance is measured should bear on the commutator with normal pressure.

(2) The peripheral speed of the commutator must be at least 2 metres per second.

(3) The testing current should be equal to the normal current of one brush $\left(\text{viz.} = \frac{2c}{m}\right)$. The resistance should be also measured with a quarter, half, and three-quarters of this current.

(4) Before the measurement the machine should run if possible for some hours with full load.

These specifications apply only to tests where a great accuracy is required. In many cases it will be sufficient to determine the contact resistance of carbon brushes by the indirect method. The resistance is measured first between the machine terminals, and afterwards between the commutator bars—the difference representing approximately the contact resistance.

In practice the contact resistance with metal brushes is generally neglected.

Finally, with the arrangement described previously, if the contact resistance of the two brushes in series is equal to $r_1$, and the total number of brushes as before be $m$, the total contact resistance $r$ is given by equation—

$$r = \frac{2r_1}{m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

## The Brush Resistance

The measurement of the very small brush resistance can also be made by any of the three methods described. This resistance (of a single brush) is taken between the contact surface and the point where the current leaves the brush. With metal brushes this point is generally at the middle, or even below the middle of the brush (see Fig. 64). The resistance of these brushes is therefore negligibly

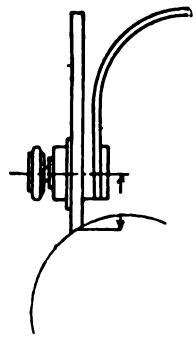


FIG. 64.

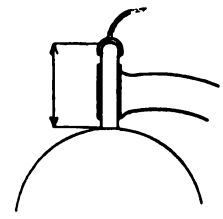


FIG. 65.

small. With carbon brushes the current is generally taken off at the end of the brush. On account of the far greater specific resistance, the resistance of carbon brushes cannot therefore be neglected. In measuring the brush resistance the contact resistance must be excluded, and as in the case of the latter, for a practical measurement the brush resistance is not obtained separately. The same refers to the resistance of the cable connecting the brush-holder pins with the main terminals.

All these resistances can, however, be measured together, as in the next experiment.

## The Total Armature Resistance

### Experiment No. III

*Measurement of the Total Armature Resistance.*

For diagram of connections, see Fig. 55 or 56.

Instruments and apparatus required—as for the above connections.

*Experiment.*—The total armature resistance is obtained either by the indirect or the comparison of deflection method. For machines of capacities up to 200 or 300 K.W., the total resistance will hardly be less than 0·001ω, consequently the Double Bridge method will not be needed.

We know that the total resistance is combined of various constituent resistances, one of which is the contact resistance. We know further, that the latter forms in some cases a considerable part of the total resistance. Hence, in measuring the latter, we must consider all the circumstances which affect the contact resistance, viz. the armature must rotate with a peripheral speed of the commutator of at least 2 metres per second, and the measuring current should be equal to the normal working current of the machine; and finally, care taken that the contact between brush and commutator is perfect. The condition of rotation of the armature involves a difficulty. Owing to residual magnetism of the magnet frame, an E.M.F. is induced by the rotating armature, which either increases or decreases the measuring current, but in either case causes an incorrect determination of the total armature resistance. To eliminate this E.M.F., the residual field is destroyed during the measurement by passing a reverse current through the field winding. To find the current strength required to annul the residual field, connect a millivoltmeter across the armature terminals. The field current has then to be varied until, with the rotation of the armature in either direction, the voltmeter shows no deflection.

A more reliable but not quite as accurate a method is to measure the resistance (with the stipulation regarding speed, normal current, etc.) with the armature rotating first clockwise, and secondly counterclockwise. We then get two different values, from which the mean is calculated. It is important that the speed be identical in both measurements.

EXAMPLE III.

*Measurement of Total Armature Resistance (Indirect Method).*

Armature (machine), No. 12519, 100 volts, 10 amps.

Instruments used—Weston Millivolt-ammeter.

Measured when cold. Air temperature, 16·5° C.

RECORD OF RESULTS.

| Amps. | Volts. | Resistance. | Mean resistance. | Remarks. |
|---|---|---|---|---|
| 2·88 | 2·6 | 0·90 | 0·90 | Clockwise |
| 2·9 | 2·65 | 0·91 | | Counter-clockwise |
| 4·51 | 3·68 | 0·81 | 0·84 | Clockwise |
| 5·26 | 4·6 | 0·87 | | Counter-clockwise |
| 6·6 | 5·3 | 0·80 | 0·82 | Clockwise |
| 6·61 | 5·58 | 0·84 | | Counter-clockwise |
| 9·2 | 7·1 | 0·77 | 0·80 | Clockwise |
| 9·22 | 7·7 | 0·83 | | Counter-clockwise |
| 11·7 | 8·9 | 0·76 | 0·77 | Clockwise |
| 11·0 | 8·7 | 0·79 | | Counter-clockwise |

Fig. 66 shows the relation between the total resistance of this armature and the current strength.

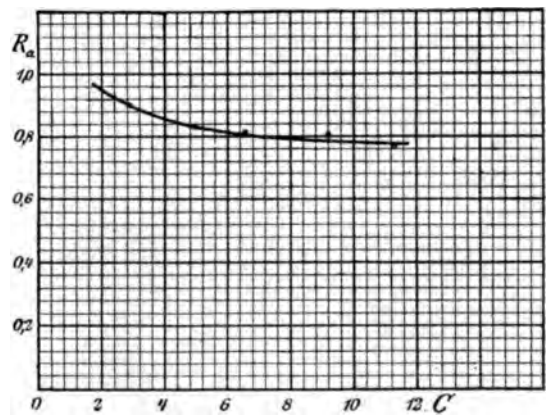



FIG. 66.

## The Field Resistance

There are no difficulties in measuring the field resistance. The choice of the method depends solely on the type of field winding, *i.e.* whether series or shunt wound.

### (*a*) Shunt Windings.

Since the resistance of a shunt winding is always relatively high, the indirect method need only be chosen. The field may be impressed directly with the full machine voltage, but the readings must be taken quickly, so that no material heating of the winding can take place. As with every resistance measurement the temperature of the winding has to be considered, it is of course best to measure the resistance when cold, viz. when the temperature of the winding is that of the surrounding air.

Owing to the high self-induction of the field winding, care must be exercised in switching the voltmeter in and out of circuit, otherwise the self-induced current may damage the instrument. The following procedure should be employed: Close the field, then the voltmeter circuit, make the requisite measurements, open the voltmeter circuit, and finally, for the *status quo* condition, break the field.

### (*b*) Series Windings.

The resistance of series windings is comparatively low—with machines of medium size about equal to the armature resistance. Thus with series windings the comparison of deflection method will generally be employed, and with small machines the indirect method. With regard to temperature, the previous remarks are applicable.

With compound windings the resistance of the series and shunt windings are measured separately.

# CHAPTER III

# MEASUREMENT OF TEMPERATURES

## General Remarks

ONE of the most important factors for judging the quality of a continuous current machine is its overheating after a full load run of some hours.

There are three conditions which a good machine should fulfil, viz. high efficiency, long life, and low price. The life of a machine depends mainly on its overheating; the warmer the winding of a machine becomes, the greater is the danger of the insulation, which consisting mostly of organic substances, becoming carbonized, and hence useless.

With a given output the overheating depends on the size of the machine. The larger the cross-sectional areas of both the electrical conductors and the magnetic circuit, the smaller will the overheating be, but on the other hand the machine will be heavier and of greater cost. Thus the conditions of cheapness is inverse to that of the life and high efficiency of the machine. In buying a machine it would not be policy therefore to consider the price and output only, but its efficiency and probable period of life should likewise be duly considered. The determination of efficiency will be fully dealt with in a subsequent chapter. We shall discuss in turn the other desiderata of a good machine, viz. minimum of overheating, high insulation resistance and dielectric strength, etc., and the measurement of the same.

The temperature of a winding can be measured in three different ways, viz.—

(1) Directly, by a thermometer on the surface of the winding.

(2) Indirectly, by placing a thermo-cell either on the surface or inserting it in the interior of the winding.

(3) Indirectly, by measuring the resistance of the winding and comparing it with that at a known temperature.

The first of these three methods is doubtless the simplest, but the least accurate. In placing the thermometer on the winding care must be taken that the contact is good. For this purpose the bulb of the thermometer should be wrapped with tinfoil, then pressed on the winding, and the exposed part covered with cotton wool. The thermometer bulb should be small. In some cases the use of specially shaped bulbs is of advantage. The maximum temperature reached by the thermometer is taken as the reading. If the temperature of a winding is measured while the machine is working, great care must be observed not to place the thermometer in the neighbourhood of an alternating field, otherwise currents will be induced in the mercury which might considerably affect the reading. Where necessary alcohol instead of mercury thermometers should be employed.

It is obvious that such measurement of temperatures by means of a thermometer can only be relatively, but never absolutely, correct. The inner inaccessible parts of a winding are always warmer, sometimes considerably warmer, than the surface. Thus the temperature measured by the thermometer will always be lower than the true temperature of the winding. We shall see later on in some examples that the difference between the true and thermometrically measured temperatures may be very considerable. It is therefore always necessary to specify exactly where the temperature was measured.

With windings which, owing to their large surface, dissipate heat very quickly, the temperature must either be measured during the running of the machine or by the second alternative described later.

The measurement of temperatures by means of thermo-electric junctions is mostly confined to temperatures exceeding 500° C. It may, however, be applied to determine the lower temperature of dynamos. For this purpose an antimony-bismuth junction is the best. The E.M.F. of such a thermo-cell is about 90 microvolts per 1° C. The voltmeter (or galvanometer) used should be calibrated directly in degrees C., since the E.M.F. of a thermo-electric junction varies directly with its temperature within small limits only.

The measurement of temperature by thermo-cells is of special advantage in the case of points inaccessible to ordinary thermometers.

A simultaneously simple and exact mode of measuring the temperature of windings depends upon the variation of the resistance of conductors with temperature. The following equation shows the law of variation :—

$$r_t = r_o(1 + at) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where

$r_o$ = resistance of the conductor at 0° C.,
$r_t$ = resistance at $t$° C.,
$a$ = temperature coefficient of the conductor,

or, as in most cases, the resistance is first measured at the temperature of the air ($t_1$°)—

$$r_t = r_{t_1}\{1 + a(t - t_1)\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Thus the overheating T($= t - t_1$) is given by—

$$T = \frac{r_t - r_{t_1}}{r_{t_1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The temperature coefficient for copper varies between 0·0038 and 0·0044. For exact measurements the coefficient should be obtained experimentally, but for practical purposes it is quite sufficient to assume $a$ as 0·004.

The overheating can be easily determined if $r_{t_1}$, the resistance of the winding when cold (*i.e.* at the temperature of the surrounding air), and $r_t$, the resistance when hot, are measured. The accuracy of this determination depends upon the accuracy with which the resistances are measured. With high resistances the measurement is comparatively simple, and hence the determination of the overheating offers no difficulties. The measurement of very small resistances (as the armature of large machines) is a difficult one, and liable to an error of about ± 3 per cent. Hence, if errors are made in the measurement of $r_t$ and $r_{t_1}$, the difference of these quantities may lead to a total error of 6 per cent., and in the calculated overheating an error of $\frac{0{\cdot}06}{0{\cdot}004} = 15°$ C. may occur. Hence this indirect method of measuring temperatures is almost exclusively used for windings of comparatively high resistance, *i.e.* field coils and small armatures.

The following is a variation of the indirect method: A flat coil, consisting of very fine platinum wire, is pressed against the winding, and from the increase of the resistance of this wire, its temperature, and hence that of the winding, can easily be determined.

The temperature, as measured by the direct method, is that of the coolest part (surface), and by the indirect method, the *average* of the interior and surface temperatures. This average will obviously be greater than the temperature obtained by the direct method, and in this direction lies the superiority of the indirect method.

## Measurement of the Temperature of Armatures

The temperature of armatures can be obtained by any of the methods described above. It has been stated that with large machines the indirect method offers difficulties, inasmuch as the

measurement of the armature resistance cannot always be done with a sufficiently great accuracy, and the result is considerably affected by small differences in the resistance measurement. Thus with large armatures (or generally with all armatures) the temperature should be measured by a thermometer.

With small armatures (especially for higher voltages) the indirect method gives satisfactory results, provided the measurements are made very carefully. Obviously the armature resistance, and not the total resistance, is to be measured. The latter would give an entirely erroneous result, as the contact resistance which forms a considerable part of the total resistance varies but little with the temperature, whilst, with carbon brushes, it even decreases with increasing temperature. (For measurement of armature resistance, see Chapter II.)

The temperature measured by the indirect method lies between the maximum and minimum temperatures existing in the armature. The former exists in the middle of the armature at the bottom of the slots, and the latter on the surface of the windings which cover the ends of the armature. The difference between the temperature measured and the maximum temperature actually existing depends cn the size and construction of the armature, and especially on the depth of the slots.

The following measurements have been made on the armature of a 15 B.H.P. motor of standard construction, which will give some idea of the distribution of temperature in an armature :—

| | |
|---|---|
| Temperature, measured by indirect method (mean temperature) ... ... ... ... ... | 39° C. |
| Maximum temperature (middle of armature at the bottom of slots) ... ... ... ... ... | 43° C. |
| Lowest temperature (winding at ends of armature) ... | 34° C. |

As mentioned above, the temperature of the armature should always be measured by a thermometer, which should be applied on the surface centre of the armature. With short armatures the temperature difference between the middle and ends of the armature is small, but still it must be remembered that on the surface of the middle of the armature the temperature is not the maximum. As a matter of fact the further from the surface centre the temperature is measured the greater the divergence from the actual maximum.

With regard to the maximum overheating permissible, see Chapter XI.

## Measurement of Temperature of Field Windings

The indirect method is the most accurate for measuring the field winding temperatures. The resistance of the winding is observed at a known temperature and at the temperature to be determined—from the difference in resistance, the temperature difference is calculated. For the resistance measurement the indirect method is generally employed, owing to its simplicity. The temperature thus measured lies between the surface temperature and that existing in the interior of the coil. The difference between these is generally considerable, especially with coils of great depth. For exact measurements the magnets are sometimes wound in a number of sections. If the resistances of the single sections are measured, their temperatures are then obtainable. The latter can also be found by inserting thermo-cells at different points of the winding. Sometimes tubes are provided in the magnets reaching nearly to the bottom of the coil, through which thermometers are placed, and the temperature of the interior thus measured. The measurement of temperature of field coils by means of a thermometer on the surface gives results which are sometimes as much as 100 per cent. out, and unless the above tubes are provided thermometers should therefore never be used.

The following example gives a rough estimate of the distribution of temperature in field coils. In Figs. 67 and 68 the two coils A and B are shown in section.

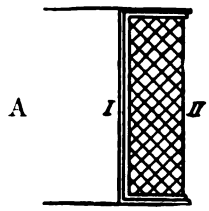



FIG. 67.

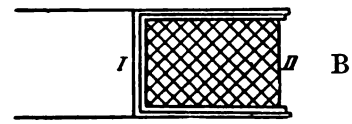



FIG. 68.

COIL A.

| | |
|---|---|
| Mean temperature (by measurement of resistance) ... | 42° C. |
| Temperature at I. ... ... ... ... ... | 49° C. |
| Temperature at surface (II.) ... ... .. ... | 38° C. |

COIL B.

| | |
|---|---|
| Mean temperature (by measurement of resistance) ... | 41° C. |
| Temperature at I. ... ... ... ... ... | 63° C. |
| Temperature at surface (II.) ... ... ... ... | 35° C. |

## Measurement of the Temperature of Commutators

This temperature can of course be only measured directly. Care should be taken to ensure a good contact between the commutator and the bulb of the thermometer.

For further remarks on the measurement of temperatures, see Chapter XI.

# CHAPTER IV

# INSULATION MEASUREMENTS

In the general remarks of Chapter III. we have referred to the importance of the insulation resistance and dielectric strength in the life of a machine (see p. 49). According to the latest views, it is far more important to test the insulating or dielectric strength of a machine than its insulation resistance. Dielectric strength is understood to represent the voltage which the insulation can withstand without breaking down. It is obvious that this voltage should be considerably higher than the normal working voltage of the machine.

Notwithstanding the smaller importance of the insulation resistance, its measurement will be fully described, as it gives under certain circumstances an idea of the insulation of the machine, and is specially suitable for finding out earth connections and short circuits.

## Measurement of Insulation Resistance

The measurement of the insulation resistance can be made in the same manner as the measurement of resistance of a conductor. As, however, the insulation resistance is generally very large, special combinations of apparatus are frequently used, some of which will be described later.

With continuous current machines the knowledge of the following insulation resistances is essential:—

(1) Insulation resistance of the armature winding to the armature core.

(2) Insulation resistance of the commutator to the commutator boss.

(3) Insulation resistance between consecutive commutator bars.

(4) Insulation resistance of field coils with respect to the magnet frame.

(5) Total insulation resistance of the machine.

To measure the insulation resistance between the armature winding and core, the conductors connecting the ends of the single coils with the commutator bars must be taken off the latter. The ends of these connectors are either attached by means of screws, or soldered to the commutator. (In the latter case the insulation resistance of the armature winding with reference to the core cannot of course be measured, but must be included in the insulation resistance named under (2).) The resistance is taken between one of the connectors and the armature shaft. With armatures having several independent windings, a corresponding number of wires have to be connected (one from each winding), and the resistance measured between these and the shaft.

To measure the insulation resistance of the commutator bars to the iron boss, the connectors between the ends of the coils and the commutator bars have, as before, to be taken off. Thin wire should be wound several times round the commutator, and the resistance between this wire and the shaft is the insulation resistance required.

For measuring the insulation resistance between the commutator bars, the copper wire must be removed and the resistance measured between consecutive bars in turn. This resistance is sometimes very low, more especially with new machines which have not yet been run. In turning up the commutator the bars are frequently bridged with fine copper dust; the commutator bars should therefore not be connected with more than 50–70 volts, especially as with good machines the potential difference between any pair of consecutive bars is hardly more than 25 volts, and with the majority only 10–15 volts.

Metallic connections between adjacent bars can either be removed by carefully scratching the surface of the insulation by means of a special tool, or by burning it out by a current.

In many cases the total insulation resistance of the armature only is measured. A commutator bar is then used as one pole and the shaft as the other (the connections between armature and commutator not being then broken).

For measuring the insulation resistance of the field coils to the iron frame, the two ends of the former are disconnected from the main terminals. The resistance is measured between one of the ends and the iron frame.

To measure the total insulation resistance of a machine the latter must be ready for running, *i.e.* the brushes resting on the commutator, the ends of the field winding (or at least one of them) connected to their main terminals, etc. The resistance is measured between one

main terminal (to which the end of the field winding must also be connected) and the iron frame or earth.

The simplest method for finding the insulation resistance is as follows: The poles of a battery of known voltage E are connected with the points between which the insulation resistance is desired, and an ammeter of known resistance $r_a$ is inserted in the circuit. If E is rather high (50 volts or more) a variable resistance R should also be provided. It may be stated here that the insulation resistance of a machine should be tested with at least that voltage for which the machine is built.

The connections are made as in Fig. 69.

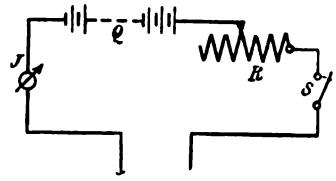


FIG. 69.

If, after closing S, the ammeter shows no deflection or a small one, R is reduced, and if necessary short-circuited.

Let $r_i$ be the insulation resistance.

Then—

$$C = \frac{E}{r_i + r_a + R}$$

and

$$r_i = \frac{E}{C} - (r_a + R) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Frequently voltmeters are used for testing insulation resistances. Let E be the testing voltage, then if $E_1$ is the voltage between the points whose insulation resistance is to be measured (see Fig. 70)—

$$\frac{E}{E_1} = \frac{r_a + r_i}{r_a}$$

thus—

$$r_i = \left(\frac{E}{E'} - 1\right) r_a \quad . \quad . \quad (11)$$

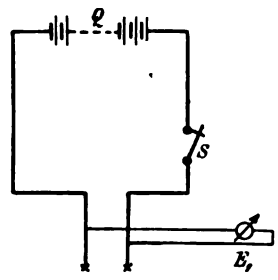


FIG. 70.

where, $r_a$ stands for the voltmeter resistance.

For this test any kind of voltmeter may be used. It is simplest to calibrate such an instrument directly as an ohmmeter (see Fig. 71). The instrument will of course read correctly only with the testing voltage for which it has been calibrated. The instrument may,

however, be provided with another scale reading volts, so that the testing voltage can be checked.

FIG. 71.

The total insulation resistance of a machine may also be tested as follows:—

Let the machine to be tested be run with full voltage, but no load, and measure by means of a voltmeter having a resistance $r_a$—

(1) The voltage between the two machine terminals A and B,

(2) The potential difference between one terminal A and the iron frame (or earth),

(3) The potential difference between the second terminal B and the iron frame (or earth).

The total insulation resistance is given by the formula—

$$r_i = \frac{V - (v_1 + v_2)}{v_1 + v_2} \cdot r_a \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where

$V$ = voltage between A and B,
$v_1$ = voltage between A and earth,
$v_2$ = voltage between B and earth.

FIG. 72.

For a rough but rapid measurement of insulation resistances, special sets are in use. They generally constitute a galvanoscope and a small battery or magneto-generator (the latter being worked by hand).

The former instruments (see Figs. 72 and 73) are generally arranged so that they can

be used with the normal supply voltage. They have in this case two or more scales; the insulation resistances corresponding to the deflections can then be read off the tables attached to the instrument.

These instruments have the disadvantage that their readings are influenced by neighbouring machines, currents, etc. On the other

FIG. 73.

hand, their simplicity and ease of manipulation render them very advantageous.

The apparatus fitted with small magneto-generators are somewhat better, the testing voltage with these being about 200–300 volts.

The cheapest instruments of this kind contain an electric bell instead of a galvanoscope (current being supplied by a few cells). The measurements are then of course only relative. These apparatus are, however, sufficient for disclosing short circuits.

## Lord Kelvin's Insulation Testing Set

This set consists of—

(*a*) A highly sensitive galvanometer, the deflection of which is proportional to the current flowing through it (see Fig. 74).

(*b*) A controlling magnet CM.

(*c*) A set of shunts, by means of which the galvanometer current may be reduced to $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{500}$ of the main current.

(*d*) A set of compensating resistances ER, which are switched in or out by the shunt switch SS. The function of these resistances is to keep the resistance of the galvanometer circuit constant when the galvanometer is shunted.

(*e*) A throw-over switch GS, by means of which the battery current can be sent through either the galvanometer only or the latter in series with the insulation resistance to be measured.

The insulation resistance is measured as follows:—

Connect one end of the winding (the insulation resistance of which to earth is wanted) with $L_2$, and connect $L_1$ to earth or the frame of the machine. The instrument is next levelled, and by means of the controlling magnet the pointer is brought to zero. Switch GS must be open.

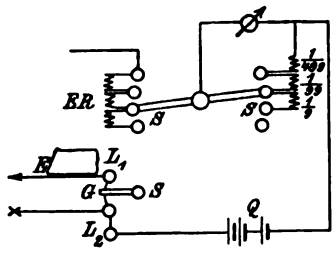



FIG. 74.

The shunt lever is placed on 1/499, GS on $L_2$, and the galvanometer deflection observed. Should it be too small, SS is moved to 1/99, 1/9, etc., until the deflection is sufficiently large. Both the position of the lever and the deflection of the galvanometer are noted.

The lever GS is then shifted to $L_1$, and again SS moved until the deflection is large enough. The position of SS and the deflection of the galvanometer is again observed.

Let $a_1$ be the deflection of the galvanometer in degrees with the lever GS on $L_2$;

$a_2$ the deflection of the galvanometer in degrees with GS on $L_1$;

$n_1$, $n_2$, $n_3$, and $n_4$ the possible positions of SS;

$n_a$ and $n_b$ corresponding positions of lever SS with GS on $L_1$ and $L_2$;

$r_a$ the resistance of the galvanometer circuit.

Then—

$$r_i = \frac{a_1 n_a r_a}{a_2 n_b} - r_a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

With SS on positions—

$$n_1 \ldots n_a \text{ or } n_b = 1$$
$$n_2 \ldots n_a \text{ or } n_b = 10$$
$$n_3 \ldots n_a \text{ or } n_b = 100$$
$$n_4 \ldots n_a \text{ or } n_b = 500$$

*Example of an Insulation Test of an Armature by means of Kelvin's Insulation Testing Set.*

Armature, No. 3460. Voltage, 220.
Current, 20 amps.
Testing voltage, 110 volts.
(*a*) Galvanometer only—
Lever SS on $n_3$, deflection = 22
(*b*) Galvanometer + armature—
Lever on $n_3$, deflection = 10

$$r_a = 50{,}000\omega$$
$$r_i = \frac{22 \times 100 \times 50{,}000}{10 \times 100} - 50{,}000 = \mathbf{60{,}000\omega}$$

## Measurement of the Dielectric Strength

If the opposite sides of a disc of insulating material are connected with a source of E.M.F., the insulating material will be pierced through if the applied voltage is high enough. This phenomenon may be explained as follows: Owing to the ohmic resistance at some point being smaller than at other points, a current passes through the (insulating) material, and thus heating takes place at this point. If the temperature rises to the point of ignition, the material breaks down and a discharge passes through, provided that the thickness of the insulating material is not larger than the sparking distance in air for the same applied voltage.

To judge the state of the insulation of a machine such a test is of great value, inasmuch as the weakest points of the insulation are found out.

As the heating for a given voltage is naturally a function of time, it is insufficient to apply the testing voltage for a short time only. It is necessary to increase the temperature of the weakest points to such a degree that the piercing through of the material is facilitated. The time required varies for the different insulating materials. The safety against deterioration of the material at normal voltage will be greater the higher the value of the piercing voltage.

With regard to the testing voltage and the length of time this voltage should be applied, see Chapter XI.

With reference to the points to which the testing voltage should be applied, the same are taken as in the measurement of the insulation resistance.

The experiment itself is very simple. After making all the requisite connections, the source of E.M.F. is brought to the voltage required, and impressed for a certain time. If the insulation gives way, which is noticed by a small detonation, and sometimes also by

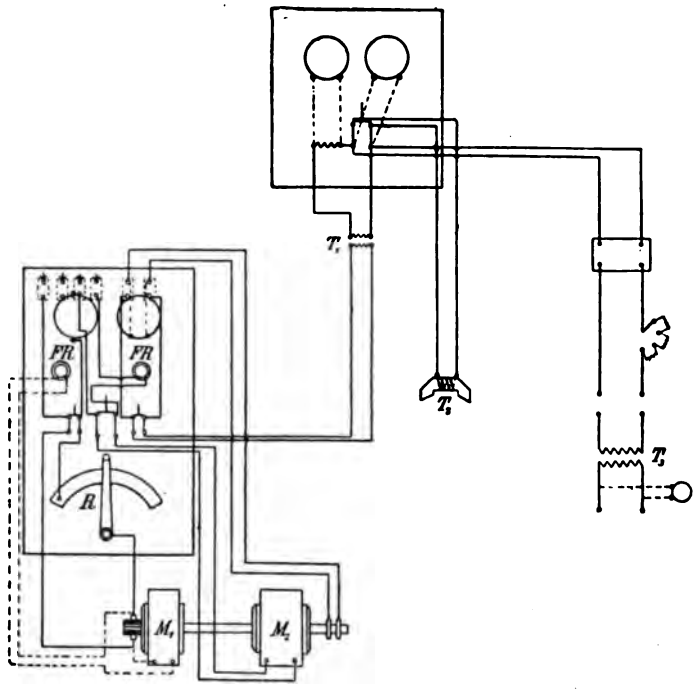



FIG. 75.

a little cloud of smoke arising at the breakdown point, the circuit has immediately to be broken.

Sometimes the point where the material has failed cannot be detected by the eye. In this case the insulation must be burned away, *i.e.* the circuit has again to be closed and a small voltage applied. It is gradually increased when, owing to the decreased resistance at the breakdown point, a relatively large current will flow through it, and burn a big hole in the material, which becomes easily apparent to the eye.

For testing the dielectric strength of a machine, alternating current is mostly used. In testing a continuous current machine with an alternating pressure, we must take into account that the maximum voltage of an alternating pressure is equal to 1·4 times its virtual value.

The connections of the source of pressure, transformers, etc., used for testing dielectric strength depend on the special circumstances, and on the machines, transformers, instruments, etc., available. A special diagram of connections for this test can therefore hardly be given.

As an example of the arrangement of such a testing set, that shown in Fig. 75 may serve. It is employed at the Union Electric Company's works.*

A continuous current motor $M_1$ drives an alternator $M_2$ of about 5–10 K.W. capacity. The field currents of both machines can be varied by the regulators FR (speed regulation for $M_1$ and voltage regulation for $M_2$). R is a starting resistance for $M_1$. Two transformers, $T_1$ and $T_3$, are provided; XX are the high tension terminals for testing the insulation of windings to earth or insulation between two windings.

$T_2$ is half of a transformer. Its purpose is to test windings embedded in the machine. The frame of the machine is employed to complete the magnetic circuit of this half-transformer. The winding shown on $T_2$ is the primary, and the winding of the machine under test serves as the secondary of this transformer.

* From Niethammer's "Electrotechnisches Practikum."

# CHAPTER V

## MEASUREMENT OF SPEED

WITH many of the experiments described later the accuracy of the result depends chiefly on the accuracy with which the speed is measured. Hence a certain amount of skill in measuring speeds is essential.

The type of instruments used for speed measurement depends entirely on the circumstances under which the measurement is made. If the speed ($n$) is very low it can be counted directly. For this purpose at any point of the rotating part (as, for instance, on the surface of a belt pulley) a mark is made. When this appears in sight a stop-watch is started, and the number of passages of the mark is counted within in a certain time. In order to reduce the unavoidable errors due to starting and stopping the watch, the revolutions should be counted for at least 1–2 minutes.

This kind of speed measurement may be varied somewhat by providing the pulley or any other rotating part of the machine with a striker; the latter strikes a bell at each revolution. In this way speeds up to 150–200 r.p.m. may easily be measured.

Another very simple though not quite as exact a method for measuring the speeds of belt-driven machines only, is the following: On the outer surface of the belt a mark is made, and the number of times it appears to the observer, say in one minute, is noted. If the total length of the belt be $l_1$, the diameter of the belt pulley of the machine $d$, the required speed of the latter $n$, and the number of complete revolutions of the belt $n_1$, then the speed—

$$n = \frac{l_1}{\pi d} \cdot n_1$$

where $l_1$ and $d$ are of course expressed by the same units.

In this manner high speeds (1000–2000 r.p.m.), can be measured provided that the ratio between the length of the belt and the pulley

diameter is large. Owing to the slip arising between the belt and pulley this method is not absolutely correct; however, it is quite sufficient for approximate measurements.

The simplest direct reading instrument for measuring speed is the speed counter. It usually consists of a shaft or spindle, which is partly threaded, and provided with a pointed tip. The shaft engages with and rotates a toothed wheel. A pointer above the latter directly indicates the number of revolutions. In measuring the speed with such an instrument the pointed tip is pressed into a central hole in the shaft of the machine. The position of the shaft of the speed counter must be such as to avoid slip between it and the shaft of the machine. A little practice in this measurement will be needed. If possible a small catch should be provided on the shaft of the machine, as in Fig. 76. These speed counters generally have a second pointer which registers the revolutions in thousands (see Fig. 77).

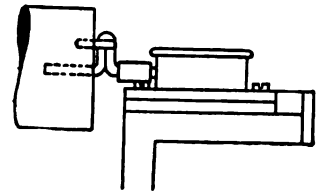


FIG. 76.

With this kind of instrument the number of revolutions per minute has to be determined by the aid of a stop-watch. The error occurring in starting and stopping the watch is avoided in the instruments illustrated in Figs. 78 and 79. The former is provided with a stop-watch. In pressing the spindle of the instrument against the shaft of the machine, the watch is automatically released, and stopped again when the instrument is withdrawn. Fig. 79 is an illustration of a counter in which the toothed wheel (or counter) is only in gear with the threaded spindle when the small lever is depressed.

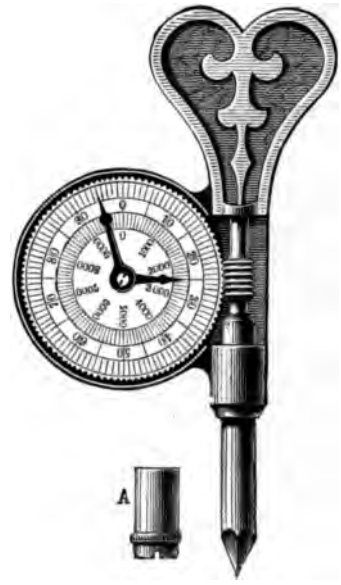



FIG. 77.

Another type of speed counter is that with moving numbers (Fig. 80). This instrument consists of a number of small drums, on the circumference of which the numbers 0–9 are stamped. The (units) drum makes one-tenth of a revolution for one revolution of the spindle of the counter, the next (tens) drum travels likewise one-tenth of a revolution for ten revolutions of the

spindle, the third (hundreds) drum for one hundred revolutions, etc. The difference between the total numbers registered before and after the measurement indicates the number of revolutions the machine has made during that period. These speed counters can also be

FIG. 78.

FIG. 79.

provided with a stop-watch, and are then the most reliable instruments for speed determination. They are especially suitable for calibrating tachometers.

With all the instruments hitherto described a certain time is

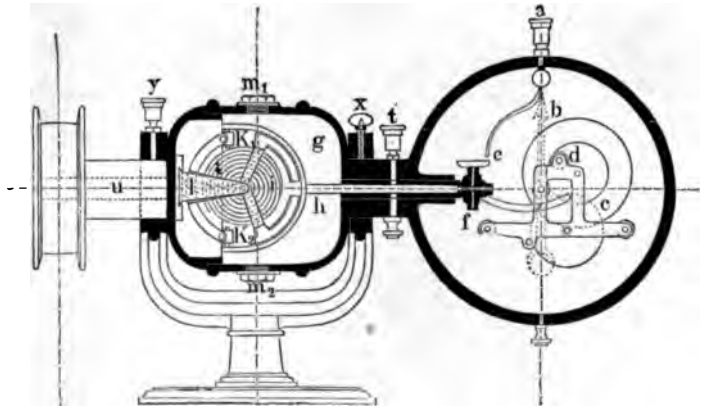
required for the measurement of speed (for exact measurements as much as 1–2 minutes is sometimes required). This is rather troublesome, especially when the speed is continually varying. In such cases tachometers are used, *i.e.* instruments indicating directly the revolutions per minute. All these instruments consist chiefly of a shaft driving a centrifugal pendulum. This pendulum opens out more or less according to the speed, thereby stretching a spring. The movement of the pendulum is transmitted by gearing to a pointer, the latter indicating the speed in revolutions per minute on a scale (see Fig. 81). These instruments are empirically calibrated.

FIG. 80.

Tachometers are constructed either for belt or cord driving, in which case they are stationary, and therefore provided with one scale only. The interior of such a tachometer is shown in Fig. 81A. Except for a regular oiling of the bearing, these instruments require no other attention.

Hand tachometers are usually provided with more than one scale. These instruments are held with both hands in the direction of, and pressed slightly against, the shaft (see Fig. 82). When changing the scales the corresponding spindle must be employed. Neglect of this precaution may lead to damage of the instrument. Recently

FIG. 81.



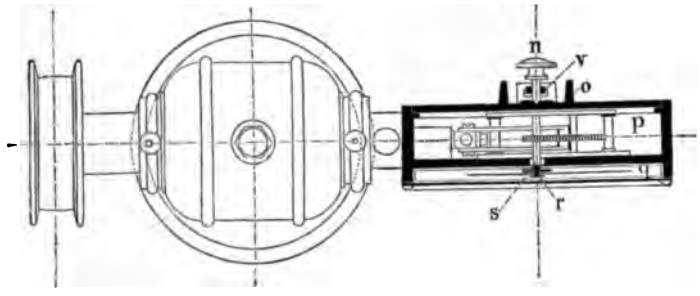




FIG. 81A.

hand tachometers have been manufactured by Dr. Horn, in which the above adjustment is avoided. These instruments are self-adjusting with regard to the speed (see Fig. 83).

Fig. 82.

Fig. 83.

There are also recording tachometers, but these are hardly of any importance for the testing of electric machines.

When measuring the speed of very small machines the energy consumed by a speed counter or tachometer is sometimes comparatively

excessive. In these cases the gyrometer of Braun or one of the optical methods is employed.

The gyrometer is a glass cylinder, partly filled with a viscous liquid, and is either directly or indirectly rotated by the revolving shaft whose speed is required. Since the cylinder is only partly filled, the liquid forms a paraboloid, the apex of which is lower the higher the speed. These instruments are calibrated empirically, and are extremely useful. A checking of these instruments is not requisite, as their constant does not vary with time. Various forms of gyrometers are shown in Figs. 84–86.

Fig. 84.

Fig. 85.

Finally, mention may be made of two appliances for measuring speed, the power consumption of which is practically zero. The first of these consists of a disc attached to the motor shaft (Fig. 87), and provided with two small weights fixed on two small levers, and projecting through two slots, which are pulled by two springs towards the centre of the disc. When the disc rotates the weights are driven outwards by the centrifugal force. The weights are painted yellow, and thus form in rotating a yellow circle, which becomes larger in diameter with increasing speed. The disc itself is black, and painted with a number of white concentric circles, which serve as

the scale of speed. In starting the motor the yellow ring becomes larger in diameter, until it reaches a certain diameter corresponding to the particular speed. This appliance is likewise calibrated empirically.

The second, a stroboscopic method, is due to Dr. Benischke.* An auxiliary motor provided with a counter has on its shaft a disc with several radially arranged slits. This motor is placed in line with the machine under test. The latter is also provided with a similar disc

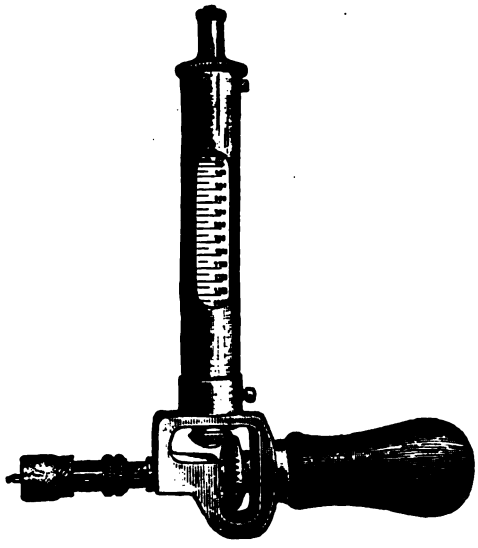


FIG. 86.

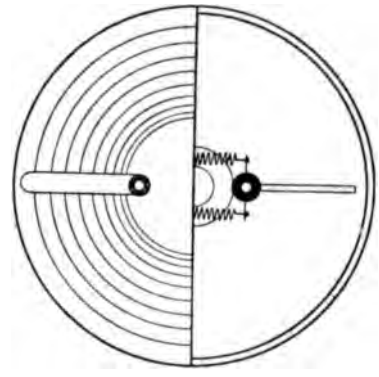


FIG. 87.

with slits. To measure the speed the auxiliary motor speed is regulated until both discs appear stationary. If the number of slits is the same in both discs, the speed of the machine will be equal to that of the auxiliary motor, and can be read off directly from the counter. If the number of slits on the auxiliary motor disc is $m$, and $n$ on that of the machine, the speed of the machine under test will be $\frac{m}{n}$ times the auxiliary motor speed.

All direct reading speed counters, *i.e.* all tachometers, must be calibrated from time to time. For this purpose the combined speed counter (with moving numbers) and stop-watch is the most suitable.

For electrical methods of measurement of speed, see Chapter VI. p. 87.

* *Electrotechnische Zeitschrift*, 1899, p. 143.

# CHAPTER VI

# NO-LOAD CHARACTERISTICS

## 1. The Shunt Machine

By no-load characteristic of a continuous current machine we understand generally to represent the curve, showing the relation between excitation (either exciting current or ampere-turns of the field magnets) and E.M.F. of a machine when running light, the speed being throughout constant.

With a shunt machine there are two possible cases, viz.—

(*a*) Separate excitation.
(*b*) Self-excitation.

In the former case, the current required to excite the machine is supplied from a separate source; in the latter case, the armature of the machine itself supplies the current required for excitation.

A curve showing the relation between the E.M.F. of a machine and its speed is also a no-load characteristic. In this the machine can either be separately or self-excited. With separate excitation we get a diagram showing the relation between E.M.F. and speed with constant excitation. With self-excitation, however, the exciting current will vary owing to the variation of E.M.F.; hence such a characteristic shows the relation between E.M.F. and speed with a variable exciting current.

Experiments IV.–VII. will thus comprise the determination of the

No-load voltage as a function of the excitation (separate) at constant speed;

No-load voltage as a function of the excitation (self) with constant speed;

No-load voltage as a function of the speed with constant excitation (separate);

No-load voltage as a function of the speed with variable excitation (self).

## Experiment No. IV

*No-load Characteristic of a separately excited Shunt Machine (Determination of the Relation between E.M.F. and Exciting Current of an unloaded separately excited Machine with Constant Speed).*

DIAGRAM OF CONNECTIONS.

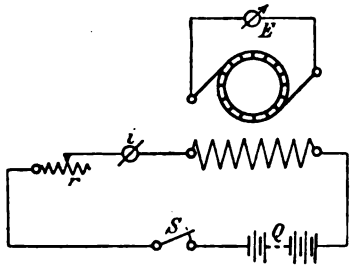



FIG. 88.

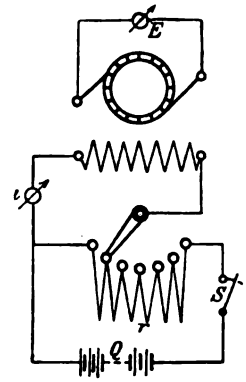



FIG. 89.

*Instruments and Apparatus required.*

E = Voltmeter (equally divided scale from 0 to about 30 per cent. above normal voltage of machine).
$i$ = Shunt ammeter (0–1½ times the normal shunt current).
$r$ = Shunt regulator.
S = Single pole switch (special field switch).
Q = Source of pressure, the voltage of which must at least be equal to the normal voltage of the machine, and preferably about 50 per cent. greater.
One tachometer.

*Experiment.*—The machine to be tested is driven by an auxiliary machine, the speed of which must be constant. If this auxiliary machine is an electric motor, it should be provided with a shunt regulator, in order to keep the speed constant.

With S open, adjust $r$ so that all its resistance is in circuit, and bring the machine to its normal speed. Since the shunt circuit is broken, the shunt ammeter shows no deflection. Nevertheless, the voltmeter will show a certain though small deflection, provided that the brushes are in the neutral position or not too far from it. This small

voltage is caused by the residual magnetism of the magnet frame, and is hence called the residual voltage. It is generally larger for machines of cast steel than for those of cast iron, and varies between 3 to 8 per cent. of the normal voltage of the machine. The residual voltage is a maximum with the brushes in the neutral zone. They should therefore be adjusted so as to obtain a maximum deflection on the voltmeter, and then left in this position during the whole of the experiment.

The speed is now measured, the residual voltage noted simultaneously, and both recorded. Next close switch S. As all the shunt resistance is in circuit, the exciting current and the increase of the brush voltage will both be very small. The shunt current and the voltage must be registered and the speed checked. Increase the exciting current by decreasing the shunt resistance until the maximum is reached, and determine for about five to ten different shunt currents the corresponding brush voltages (simultaneously measuring the speed).

Repeat then the whole experiment in the reverse order, *i.e.* weaken the shunt current gradually by inserting resistance in the shunt circuit until finally (by opening switch S) it becomes zero. It is unnecessary to determine as many points as with increasing excitation. The shunt current must be decreased continuously, and after breaking the shunt circuit determine again the residual voltage.

The readings thus obtained should be plotted as a curve with the shunt currents as abscissæ and the voltages as ordinates. If during the experiment the speed has remained constant, then the voltages read on the voltmeter are plotted as ordinates. Otherwise these voltages must be reduced to a constant speed $n'$.

If $E$ = reading on the voltmeter, $n$ = the measured speed, the corrected voltage $E'$ is given by—

$$E' = E\frac{n'}{n} \quad . \quad . \quad : \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

In the characteristic diagram $E'$ should always be the ordinate.

From this experiment we get two curves, one for ascending, the other for descending current. The latter curve will always lie above the former, this being accounted for by the residual magnetism. As in the actual working of a machine, its strength of field varies continually, for practical purposes therefore the average of these two curves should be taken.

The shape of no-load characteristics may be seen from Figs. 90 and 91. The first part of the curve is nearly straight; it then forms a more or less sharp bend until, finally, it becomes flat. The explanation for this is not difficult. Since the machine supplies a

negligibly small current—the small current flowing through the voltmeter—the voltmeter reading E will be the E.M.F. of the armature.

We have—

$$\text{E.M.F.} = \frac{\text{S}n\text{N}}{60 \cdot 10^8} \cdot \frac{p}{p'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

where S = Number of conductors,
$n$ = Revolutions per minute,
N = Total flux,
$p$ = Pairs of poles,
$p'$ = Number of sections of armature in parallel.

And as $n$, S, $p$, and $p'$ are constant in this experiment—

$$\text{E.M.F.} = \text{KN}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

*i.e.* the no-load characteristic represents the relation between the exciting current and the total number of lines of force produced by the field ampere-turns. With low inductions the number of turns required for the iron parts is very small; on the other hand, the ampere-turns required for the air gap increase proportionally with the induction, so that for low inductions the no-load characteristic is a straight line. With increasing induction the ampere-turns for the iron circuit increase more rapidly than the air gap ampere-turns —hence the bend on the curve. Lastly, with high inductions the ampere-turns of the iron path preponderate; and for a small increase of the induction the increase in ampere-turns is very great. Thus the curve becomes flatter.

The no-load characteristic shows therefore the relation between the inductions in the various parts of a machine. The smaller the air gap between armature and poles, namely, the smaller the ampere-turns for the air gap, the quicker will the E.M.F. rise, and the steeper will the ascending part of the characteristic be. Again, the smaller the ratio between the areas of the iron circuit and air gap, viz. the quicker the induction in the iron circuit grows, the sharper the bend, and the flatter will the upper part of the curve become.

It is of great practical importance to know the point on the curve at which the machine works under normal conditions. It is also essential to know whether (and how far) the voltage of the machine can be raised above the normal, without an excessive increase of the shunt current (this, for instance, is important with machines for charging accumulators). This may be seen directly from the no-load characteristic.

If the normal voltage of the machine is on the ascending branch of the curve, the machine can easily be overloaded, *i.e.* by a comparatively small increase of the exciting current a considerable

increase in voltage can be effected. But such a machine has the disadvantage that, if self-excited, its voltage is not steady enough for varying load.

On the other hand, if the normal voltage of a machine is on the upper (flat) part of the curve, then, with self-excitation, it will be less sensitive to variations of load. Such a machine is, however, more expensive on account of the greater amount of copper required for the field coils, and has the disadvantage that the voltage can only be increased by an excessive increase of the exciting current.

It may finally be mentioned that the no-load characteristic of a machine coincides with its magnetization curve if the armature pitch is equal to the width of the poles, and if the brushes are in the neutral position.

### Example IV.

*Determination of the No-load Characteristic (Magnetization Curve) of a separately excited Shunt Machine.*

Machine, No. 12519. Type and maker, D 101, Crompton & Co. Number of poles, 2.

Voltage, 100; current, 10; output, 1 B.H.P.; revolutions per minute, 1700.

Instruments used—Combined Weston Voltameter, No. 1236.

Table of Results.

| Exciting current. | Terminal voltage. | Corrected terminal voltage. | Speed. | Remarks. |
|---|---|---|---|---|
| A. Ascending magnetizing current. | | | | |
| — | 6·1 | 6.4 | 1330 | Shunt circuit broken |
| 0·038 | 10·8 | 11·4 | ,, | — |
| 0·11 | 23·0 | 24·0 | ,, | — |
| 0·21 | 42·4 | 44·0 | 1350 | — |
| 0·31 | 59·4 | 60·0 | 1380 | — |
| 0·41 | 73·0 | 74·0 | ,, | — |
| 0·51 | 84·5 | 85·5 | ,, | — |
| 0·63 | 96·6 | 98·0 | ,, | — |
| 0·74 | 105·0 | 106·5 | ,, | — |
| 0·85 | 111·5 | 113·3 | ,, | — |
| 1·07 | 122·8 | 125·0 | ,, | — |
| 1·29 | 129·8 | 131·8 | ,, | — |
| 1·49 | 133·6 | 134·6 | 1390 | — |

TABLE OF RESULTS—*continued.*

| Exciting current. | Terminal voltage. | Corrected terminal voltage. | Speed. | Remarks. |
|---|---|---|---|---|
| | B. Descending magnetizing current. | | | |
| 1·37 | 132·0 | 133·5 | 1390 | — |
| 1·17 | 127·0 | 128·0 | " | — |
| 0·85 | 115·0 | 116·0 | " | — |
| 0·61 | 99·0 | 100·0 | " | — |
| 0·42 | 80·5 | 81·0 | " | — |
| 0·22 | 50·4 | 50·5 | " | — |
| 0·1 | 26·5 | 26·8 | " | — |
| — | 6·6 | 6·7 | " | Shunt circuit broken |

NOTE.—The machine has been excited from a source having a voltage of more than twice the normal machine voltage. The speed could not be kept constant, hence all readings had to be reduced to a constant speed.

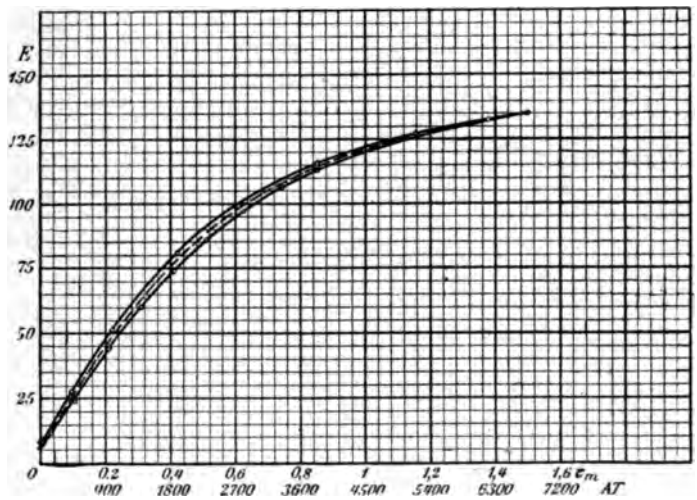



FIG. 90.

Fig. 90 shows the two curves obtained from the above results. From these curves we learn that with normal voltage of the machine (100 volts), the saturation of the iron is small, as beyond this point the voltage still grows rapidly. It follows, therefore, that the voltage

of the machine will be unsteady with varying load when self-excited. The magnet frame of this machine consists of cast iron. Since the curve has not reached its last stage (flat) with even large exciting current, we conclude that either the machine is working with a small induction in the air gap, or the ratio between the cross-sectional area of the iron and air gap is comparatively large. Between the ascending and descending curves a third (dotted line) is drawn, representing the average of the two. The total ampere-turns of the field coils as well as the exciting currents are taken as abscissæ.

Fig. 91 shows the no-load characteristic of a shunt machine for 220 volts and a normal speed of 2000 revolutions per minute. The experiment could only be performed with a speed of 1900 revolutions per minute (Curve I.), and to obtain the Curve II. for 2000 revolutions per minute, the ordinates of Curve I. have been increased in the ratio of $\frac{2000}{1900}$.

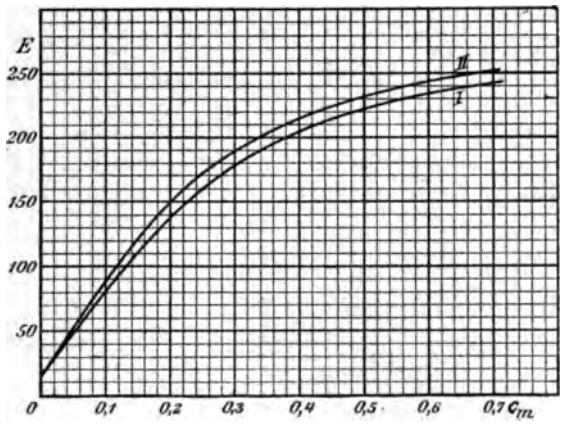



FIG. 91.

Both curves represent the average values for ascending and descending magnetization.

## Experiment No. V

*No-load Characteristic of a self-excited Shunt Machine (Determination of the Relation between E.M.F. and Exciting Current of an unloaded self-excited Machine at Constant Speed).*

DIAGRAM OF CONNECTIONS.

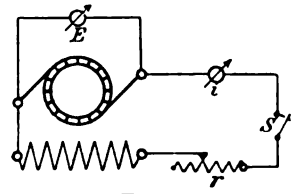



FIG. 92.

*Instruments and Apparatus required.*

E = Voltmeter (0–30 per cent. above normal voltage of machine).
$i$ = Shunt ammeter.
$r$ = Shunt resistance.
S = Single pole switch (field switch).
One tachometer.

*Experiment.*—The experiment is performed quite similarly to that of experiment No. IV. After the machine has been brought to the normal speed (S being open and all the resistance $r$ in circuit) the brushes have to be shifted to the neutral position and the residual voltage is measured. Then close S; if the resistance $r$ is very large, the shunt current produced by the residual voltage will probably be too small to cause the voltage to increase, hence $r$ must be diminished until the machine begins to excite itself. The total shunt resistance (field coils + shunt regulator) at which the machine just begins to excite itself is termed the critical resistance for the speed employed. When this resistance is reached, the voltage of the machine will increase slowly but continuously; hence with self-excitation of a machine it is difficult, in some cases impossible, to determine the initial part of the curve, especially as the slightest increase in speed causes a comparatively large increase of voltage. It is best to make the shunt resistance about equal to the critical resistance, and to wait until the voltage becomes constant at a certain point. The voltage, exciting current, and speed should then be measured. Next for various exciting currents read the corresponding voltages and determine the speed. Evidently the maximum voltage will be obtained when all the resistance $r$ is cut out, *i.e.* the field coils directly connected across the armature. After reaching this point the experiment should be made for descending magnetizing currents, and finally the shunt circuit broken by opening the switch S.

The results of this experiment are not much different to those of experiment No. IV., though in the former case the condition of no-load of the machine is, strictly speaking, not fulfilled, as the armature supplies current for self-excitation. This current, which in the case of small machines may amount to about 8 per cent., and sometimes more, of the normal full load current, causes a small armature reaction, and this combined with the ohmic drop produce a fall of the terminal voltage. The no-load characteristic curve taken with self-excitation will therefore always lie below that taken with separate excitation, and the difference between the two curves will be greater the higher the voltage, *i.e.* the larger the exciting current. For most practical purposes, however, these two curves may be regarded as identical.

Experiment V. has the advantages that an external source of

E.M.F. is not required; and the shunt resistance required is smaller than that requisite in experiment No. IV. On the other hand, the results of the latter are more accurate, and further, with a sufficiently large shunt regulator or with a parallel regulator (see p. 15) the ascending (initial) branch of the curve can be determined exactly.

It may finally be mentioned that in performing this experiment special care must be taken to keep the speed constant. A correction of the voltage is here no longer possible. With a self-excited machine the voltage is not directly proportional to the speed; as we shall see in experiment No. VII. the ratio between the voltage and speed varies with the degree of saturation, *i.e.* with the excitation. For an exact correction to the voltage another characteristic is necessary. However, we may assume as an approximation for small differences in speed—

$$E' = E \cdot \frac{n'^2}{n^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

### Example V.

*Determination of the No-load Characteristic (Magnetization Curve) of a self-excited Shunt Machine.*

Machine, No. 5059. Type and maker, International Company. Number of poles, 4.

Voltage, 220; current, 5 amps.; output, 1 B.H.P.; revolutions per minute, 1800.

Instruments used—Combined Weston Voltameter, No. 1236.

Table of Results.

| Exciting current. | Terminal voltage. | Corrected voltage. | Speed. | Remarks. |
|---|---|---|---|---|
| | A. Ascending magnetizing current. | | | |
| 0·00 | 16 | — | 1800 | Shunt circuit broken |
| 0·117 | 126 | — | 1800 | |
| 0·14 | 144 | — | 1800 | |
| 0·184 | 174 | 172 | 1810 | $\frac{174 \times 1800^2}{1810^2} = 172$ |
| 0·22 | 192 | — | 1800 | |
| 0·257 | 211 | 207 | 1820 | $\frac{211 \times 1800^2}{1820^2} = 207$ |
| 0·312 | 228 | — | 1800 | |
| 0·37 | 240 | — | 1800 | |

TABLE OF RESULTS—*continued.*

| Exciting current. | Terminal voltage. | Corrected voltage. | Speed. | Remarks. |
|---|---|---|---|---|
| | | B. Descending magnetizing current. | | |
| 0·326 | 234 | — | 1800 | |
| 0·282 | 223 | — | 1800 | |
| 0·22 | 200 | 204 | 1785 | $\frac{200 \times 1800^2}{1785^2} = 204$ |
| 0·16 | 169 | — | 1800 | |
| 0·115 | 140 | — | 1800 | |

NOTE.—Below 126 and 140 volts respectively a constant voltage could not be obtained. Brushes were in the neutral position throughout.

In Fig. 93 are drawn the two no-load curves. From these we see that a considerable part of the curves cannot be obtained, and must

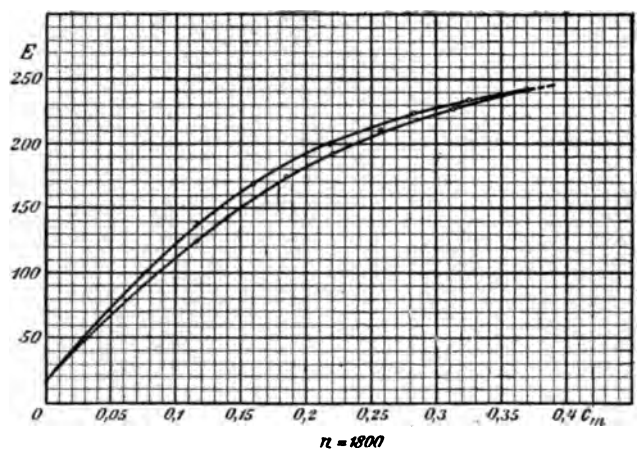



FIG. 93.

therefore be estimated. This is, however, with a known residual voltage not difficult, since we know this part of the characteristic to be nearly straight.

The no-load characteristic of the above machine has also been taken with separate excitation, and the two curves are shown in

Fig. 94. Curve I. has been obtained with separate, Curve II. with self excitation. The difference between the two curves is in this case appreciable, viz. about $2\frac{1}{2}$ per cent. in voltage (for equal excitations), or about 6 per cent. in the excitation (for equal voltages).

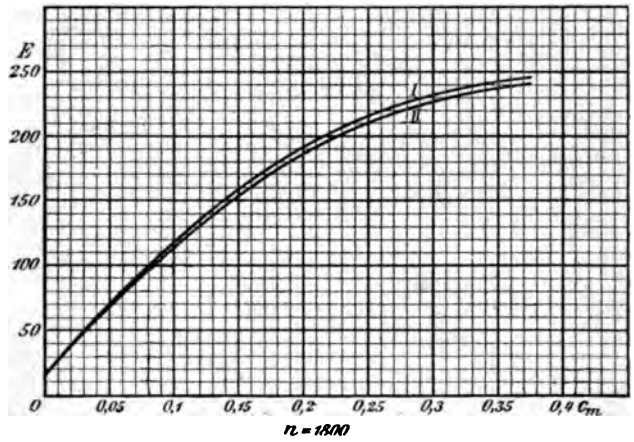



FIG. 94.

## Experiment No. VI

*No-load Characteristic of a Shunt Machine with separate constant-current excitation (Determination of the Relation between E.M.F. and Speed).*

DIAGRAM OF CONNECTIONS.

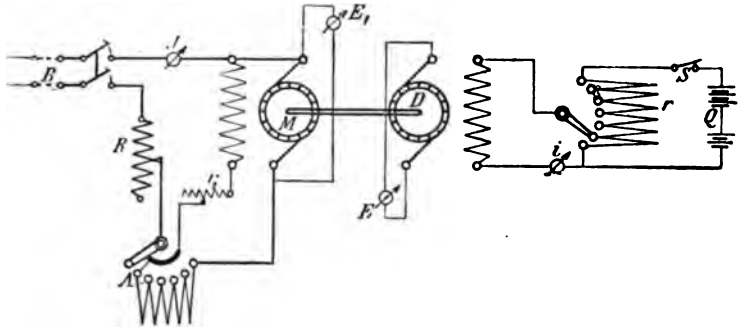



FIG. 95.

*Instruments and Apparatus required.*

(*a*) For the machine D to be tested.

E = Voltmeter, if possible for two ranges, viz. for 0–10 per cent. of, and 0 to about 30 per cent. above the normal voltage.

$i$ = Shunt ammeter.

$r$ = Shunt regulator.

S = Single pole switch.

Q = Source of E.M.F., voltage of which must be at least equal to the normal voltage of the machine under test.

(*b*) For the auxiliary motor M.

$E_1$ = Voltmeter.

J = Ammeter.

A = Starter.

$r_1$ = Shunt regulator (without a stop, on which the circuit is broken).

R = Regulating resistance.

B = Fuse.

One tachometer.

*Experiment.*—As with this experiment the speed of the dynamo and hence also that of the driving motor, must be varied within the widest limits, it is necessary to provide the latter both with a main regulator for downward regulation and with a shunt regulator for upward regulation of the speed (see diagram of connections).

Before starting M all the shunt resistance $r_1$ must be cut out, but the main resistance R all in. If the motor is started by means of the starter A, it will run with the smallest speed. Now open switch S, so that the shunt circuit of D is broken. As the voltage produced by the armature is but very small (residual voltage), the lower range of the voltmeter should be used. By cutting out part of the resistance R, increase the speed to about one-half normal; note speed and voltage of D. Then increase the speed by cutting out all the resistance R, so that M runs with normal speed. Take the same readings as before, and repeat for still higher speeds, which can be obtained by switching $r_1$ in the shunt circuit in order to weaken the field. As we shall see later on, the determination of about three to four points is sufficient.

From this first experiment we get a curve, showing the relation between speed and terminal voltage (E.M.F.) with open shunt circuit, *i.e.* the relation between speed and residual voltage. To find the curve for any excitation, close switch S, and regulate $r$ so as to get the excitation required, say $\frac{1}{5}$ of the normal exciting current. Then proceed

as above, and determine E for a few different speeds. The voltmeter must now be used with the wider range. Obtain a similar set of readings for $\frac{2}{5}$, $\frac{3}{4}$, $\frac{4}{5}$, and 1 of the normal exciting current. The larger the exciting current the less the motor requires speeding up, so that for above $\frac{3}{5}$ of the normal exciting current, the motor M need not have a speed above the normal.

If the various results are plotted (voltage as a function of speed for constant exciting current) we obtain a number of straight lines passing through the origin. The angles which these lines make with the abscissa increase with the exciting current.

We arrive at the same result by formula (15)—

$$\text{E.M.F.} = \frac{\text{S} \cdot n\text{N}}{60 \cdot 10^8} \cdot \frac{p}{p'}$$

for constant excitation N is constant, and as $\text{S}\frac{p}{p'}$, are, for a given machine, constant—

$$\text{E.M.F.} = \text{K} \,.\, n \quad . \quad . \quad . \quad . \quad . \quad . \quad (18),$$

*i.e.* the E.M.F. is directly proportional to the speed. For $n = 0$ E.M.F. $= 0$, *i.e.* the line must pass through the origin. Further, as N grows with the exciting current, the constant K must increase too, from which it follows that the angle between the line and the abscissa increases.

As a straight line is determined by two points, it would be sufficient to find a single point by experiment, the second point (the origin) being given. For the sake of greater accuracy, however, it is preferable to determine two or three points.

These curves can be found graphically from the no-load characteristic (magnetization curve), as will be shown later on.

## Example VI.

*Determination of the Relation between E.M.F. and Speed of a Shunt Machine excited with Constant Current.*

Machine, No. 44709. Type and maker, A 40, Schuckert. Number of poles, 4.

Voltage, 75; current, 533 amps.; output, 40 K.W.; revolutions per minute, 565–770.

Instruments used — Weston Millivoltmeter, No. 3416, with multiplier and Weston ammeter, No. 4214.

TABLE OF RESULTS.

| Exciting current. | Voltage. | Speed. | Remarks. |
|---|---|---|---|
| 0 | 0·65 | 440 | Curve I. |
| 0 | 1·00 | 680 | |
| 3 | 12·0 | 180 | Curve II. |
| 3 | 26·8 | 400 | |
| 3 | 37·5 | 560 | |
| 6 | 10·0 | 100 | Curve III. |
| 6 | 28·3 | 300 | |
| 6 | 44·0 | 465 | |
| 9 | 20·0 | 165 | Curve IV. |
| 9 | 48·5 | 400 | |
| 9 | 60·0 | 500 | |
| 12 | 24·0 | 180 | Curve V. |
| 12 | 36·5 | 280 | |
| 12 | 50·0 | 380 | |

The curves I.–V. in Fig. 96 are drawn from these results.

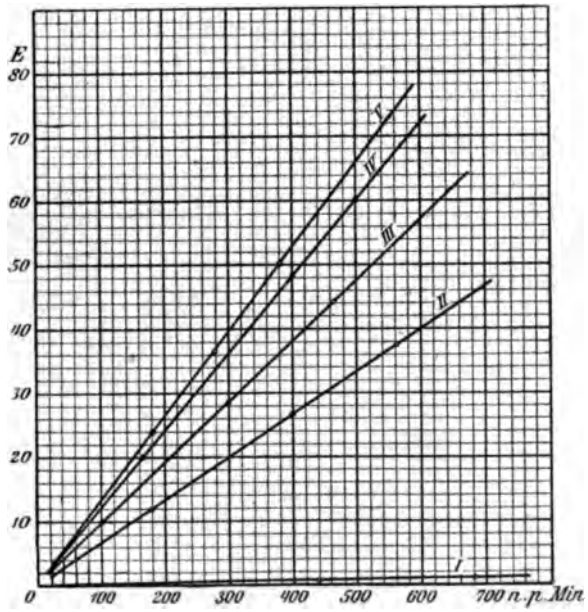



FIG. 96.

As stated before, these curves may be determined graphically from the no-load characteristic (magnetization curve). The latter indicates for any exciting current the corresponding voltage. If we desire to find for any excitation the relation between E.M.F. and speed, then from the magnetization curve, we derive the voltage corresponding to the particular exciting current, and as abscissa we have to take that speed for which the magnetization curve has been determined. Thus one point of the curve is known, and connecting this point with the origin, we get the characteristic for the particular excitation. We proceed in the same manner for other exciting currents.

This graphical method is indicated in Fig. 97. The no-load diagram is drawn first—this characteristic curve may be taken at any speed. The speed is next plotted on the abscissa to any scale, and from the speed at which the magnetization curve was determined draw a line AB parallel to the ordinate. If the relation between the E.M.F. and $n$ is required, say for $c_m = 2$ amps., draw through $c_m = 2$ (on the abscissa) the ordinate CD. The point of intersection of this line CD with the magnetization curve should be projected on AB, and thus E obtained. If a straight line be drawn through E and the origin, it will represent the required characteristic curve for $c_m = 2$. In Fig. 97 these curves are plotted for $c_m = 0, 2, 4, 6$, and 12.

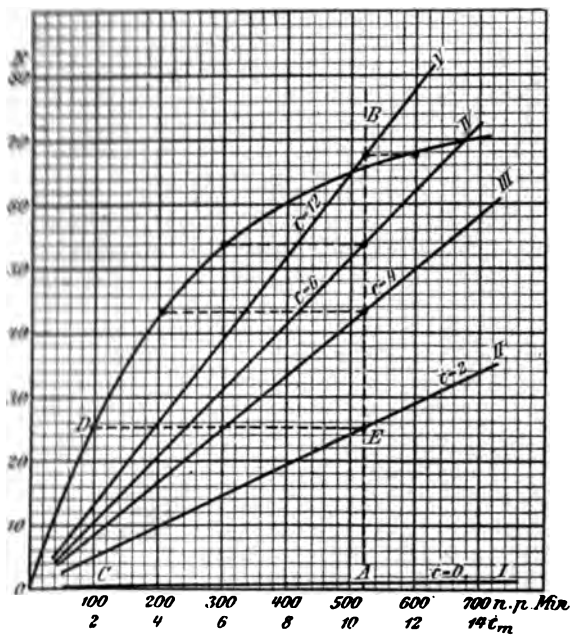



FIG. 97.

Conversely, from a number of such curves the magnetization curve can be determined by proceeding in the reverse order to that indicated in Fig. 97.

These curves have a practical application in the electrical measurements of speeds and the calibration of tachometers.

For the electrical measurement of speed any shunt machine may be employed; it is of course essential that this auxiliary machine should be small compared with the machine the speed of which is to be measured. If the curve showing the relation between the residual voltage of the auxiliary machine and its speed is known, the latter can be coupled to the machine under test, and a voltmeter with a sufficiently low range is connected across its armature terminals. The voltage is then read on the voltmeter, and from the calibration curve the speed of the machine is computed.

Instead of recording the residual voltage only, which is evidently very low, the auxiliary machine may be excited with a certain current. In this case the calibration curve, showing the relation between voltage and speed at this particular exciting current, must be known. An exact measurement is, however, here a little more difficult, as two instruments (voltmeter and shunt ammeter) must be observed. Further, it is important that the brushes should always be in the neutral position, since, as we have seen, the no-load voltage depends also on the position of the brushes.

Again, a machine (regarded as a standard) may be employed for calibrating and checking tachometers. Such a machine, however, should be used for no other purpose, otherwise the residual magnetism is liable to vary, and thence a frequent re-calibration of the machine would be necessary.

## Experiment No. VII

*No-load Characteristic of a self-excited Shunt Machine (Determination of the Relation between Voltage and Speed).*

DIAGRAM OF CONNECTIONS.

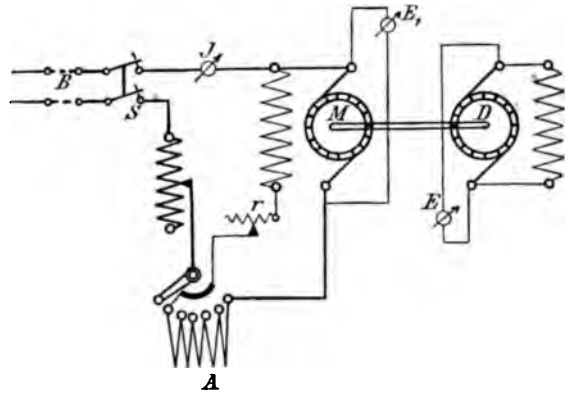



FIG. 98.

*Instruments and Apparatus required.*

(*a*) For the machine to be tested (D).
E = Voltmeter (0 to about $1\frac{1}{2}$–2 times the normal voltage).
(*b*) For the auxiliary motor M.
$E_1$ = Voltmeter.
J = Ammeter.
A = Starter.
*r* = Shunt regulator (without a break-stop).
R = Main resistance.
S = Double pole switch.
One tachometer.

*Experiment.*—With this experiment a regulation of speed within very wide limits is required; the connections of the motor correspond therefore to those of experiment No. VI. Before starting the experiment, switch all the main resistance R in and cut *r* out. Then close S and start the motor, which will run with a minimum speed. The armature voltage of D will accordingly be very small. If the voltmeter has two ranges the smaller one should be used. After having recorded both the voltage and the speed, increase the latter by cutting out part of the resistance R, and note again the voltage and speed. Repeat for different speeds, increasing the latter gradually as far as possible by cutting out the resistance R, and then by inserting shunt resistance *r* in the field circuit. Care must be taken not to weaken the field too much, as the speed may become dangerously high.

If the speeds be plotted as abscissæ and the corresponding voltages as ordinates, a curve will be obtained as shown in Fig. 99. From this curve we see that initially the voltage is low, and increases nearly proportionally to the speed. From this we conclude that the armature voltage is here only due to the residual magnetism, and that the voltage produced by the "residual" current is smaller than the residual voltage. With increasing speed the voltage produced by the "residual" current preponderates, *i.e.* the machine commences to excite itself. The curve bends here rather sharply, and immediately ascends very rapidly. The voltage at this point is rather unsteady, and it is very difficult to determine a point on this part of the curve. The rapid slope of the curve soon ceases, as at higher inductions the increase of the exciting current (due to increasing voltage) causes but a small increase of voltage, until finally the voltage is hardly influenced by the excitation. This will then only increase proportionally to the speed, *i.e.* the curve will gradually become a straight line. With a further increase of speed the voltage would no longer be proportional to the speed, as (especially with

small machines) the comparatively large shunt current would cause a considerable voltage drop.

On p. 80 it has been mentioned that in plotting the no-load characteristic of a self-excited machine, the voltage must not be corrected according to formula (14). This can be seen from the shape of the curves in Figs. 99 and 100. The formula (17) given on p. 80 is only an approximation, and should therefore be applied with caution. Thus it is important when determining the no-load characteristic to lay special stress on a constant speed of the machine.

### Example VII.

*No-load Characteristic of a self-excited Shunt Machine (Determination of the Relation between Voltage and Speed of a self-excited Shunt Machine).*

Machine, No. 12519. Type and maker, D101, Crompton & Co. Number of poles, 2.

Voltage, 100; current, 10 amps.; output, 1 B.H.P.; revolutions per minute, 1400.

Instruments used—Weston Millivoltmeter, No. 3416, with multiplier.

Table of Results.

| Voltage. | Speed. | Remarks. |
|---|---|---|
| 2 | 420 | |
| 4 | 656 | |
| 5 | 711 | |
| 7·2 | 848 | Voltage varies considerably |
| 34 | 996 | |
| 54 | 1060 | |
| 80 | 1200 | |
| 111 | 1412 | |
| 133 | 1588 | |
| 147·5 | 1722 | |
| 156 | 1800 | Speed varies |
| 166 | 1852 | |
| 175 | 1944 | |

Note.—Brushes in neutral position.

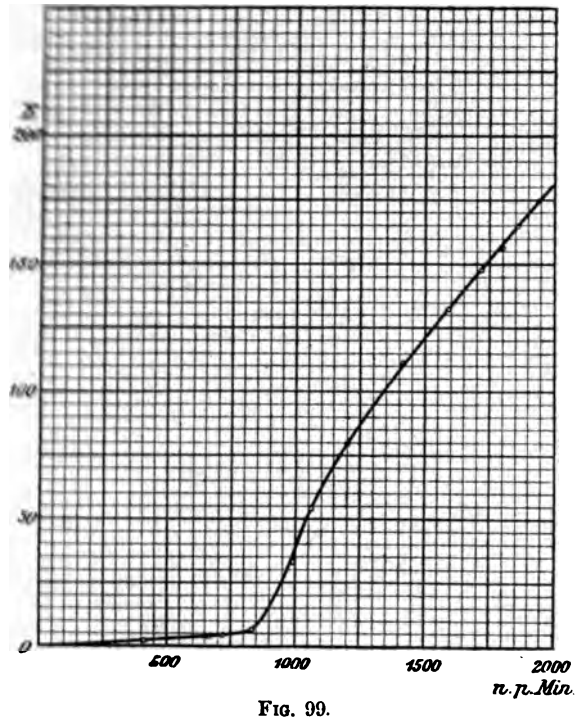



FIG. 99.

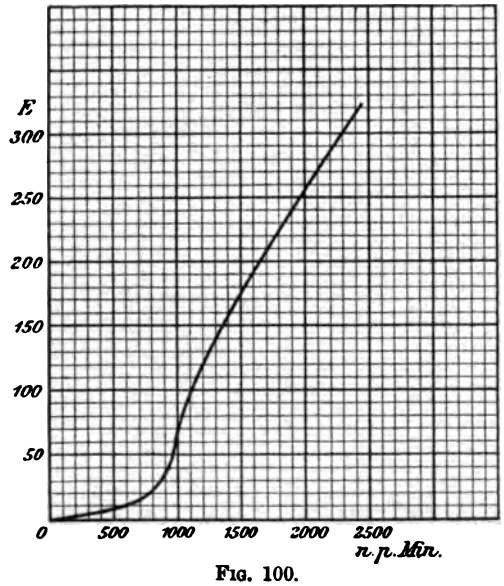



FIG. 100.

The results of this experiment are plotted in Fig. 99, while Fig. 100 represents a similar diagram of a small four-pole machine.

With all the experiments hitherto dealt with, the machine tested worked as a dynamo. A no-load characteristic of a shunt machine can, however, also be determined with the machine running as a motor. Of all the experiments which can be made in this way, there is one of special importance—viz. that by which the relation between the exciting current and speed of a shunt motor, running with a constant terminal voltage, is determined. Apart from the power required for overcoming its friction and magnetic resistance, the motor must do no work. This experiment is described in the following.

## Experiment No. VIII

*No-load Characteristic of a Shunt Motor (Determination of the Relation between Shunt Current and Speed of a Motor).*

DIAGRAM OF CONNECTIONS.

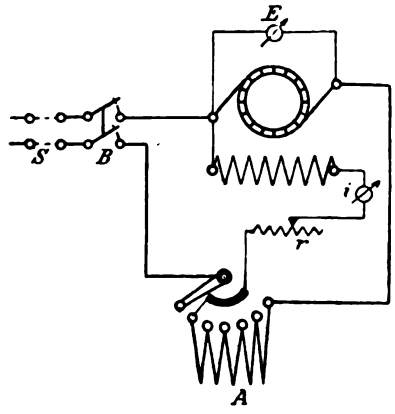



FIG. 101.

*Instruments and Apparatus.*

$i$ = Shunt ammeter (0 to about $1\frac{1}{2}$ times normal exciting current).
E = Voltmeter.
A = Starter.
$r$ = Shunt regulator (without a stop on which the field circuit is broken).
S = Double pole switch.
B = Fuse.
One tachometer.

*Experiment.*—Should a higher voltage than the normal motor voltage for excitation be not available, the motor can be connected as in the above diagram. If possible the motor should be excited from a source of 50 per cent. higher voltage than that of the motor.

First open switch S, and adjust the shunt current to the maximum value, *i.e.* the field coils directly impressed with the full exciting voltage. Then start the motor by means of the starter A. As the excitation is the maximum, the speed will be the minimum. Read the exciting current and speed, then weaken the field by inserting some resistance in the shunt circuit. The speed of the motor will consequently increase; the rate of increase will be smaller initially, and larger as the field becomes weakened. Determine the speeds corresponding to various exciting currents. When the maximum speed allowable is reached, the experiment can be repeated in the reverse order by continually increasing the exciting current, and thus decreasing the speed. With regard to the maximum speed allowable, it is difficult to state the exact limits. For well-built armatures a peripheral speed of about 80–90 feet per second is permissible. As the normal peripheral speed of small armatures is usually far below this limit, it follows that the percentage increase of speed above the normal permissible will, as a rule, be greater for small machines. Evidently a great deal will depend upon the construction of the armature winding and the commutator. The following table gives an approximate idea of the percentage increase permissible, but should be used with discretion:—

| Size of machine. | Maximum permissible increase above normal speed. |
|---|---|
| Up to 1 K.W. | 80–90 per cent. |
| „ 5 „ | 60 „ |
| „ 25 „ | 50 „ |
| „ 50 „ | 35 „ |
| „ 100 „ | 30 „ |

If the results of the experiment be plotted (with the exciting currents as abscissæ and the corresponding speeds as ordinates), a curve is obtained of the shape shown in Figs. 102 and 103. The speed of a shunt motor, according to these curves, increases with decreasing shunt currents, and *vice versâ.* This follows also from the formula—

$$\text{E.M.F.} = \frac{S \cdot n \cdot N}{60 \cdot 10^8} \cdot \frac{p}{p'}$$

Since the load and hence the E.M.F. of the motor are nearly constant—

$$n = \frac{\text{E.M.F.} \cdot 60 \cdot 10^8}{\text{S} \cdot \text{N}} \cdot \frac{p'}{p}$$

$$n = \frac{1}{\text{N}} \cdot \text{K} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

As the total flux N is a function of the exciting current, this explains the result obtained by the experiment. By transforming the ordinate scale to represent the reciprocal of the flux $\left(\frac{1}{\text{N}}\right)$, the curves then correspond to the magnetization curves, and conversely the speed-excitation curves can be derived by calculation from the magnetization curves.

As in the determination of the magnetization curve, the brush position affects the result. The brushes should therefore be in the neutral position during the experiment, or else their position be stated.

## Example VIII.

*Determination of the No-load Characteristic of a Shunt Motor.*

Machine, No. 5094. Type and make: International Company. Number of poles, 2.

Voltage, 220; current, 6 amps.; output, $1\frac{1}{4}$ B.H.P.; revolutions per minute, 1600.

Instruments used—Combined Weston Voltameter, No. 1236.

Table of Results.

| Exciting current. | Speed. | Remarks. |
|---|---|---|
| 0·335 | 1800 | Brushes in the neutral position |
| 0·293 | 1850 | |
| 0·26 | 1950 | |
| 0·24 | 2000 | |
| 0·195 | 2250 | |
| 0·18 | 2350 | |
| 0·16 | 2650 | |
| 0·145 | 2900 | |

The results of this experiment are plotted in Fig. 102. The dotted line has been obtained by actual experiment, and the full

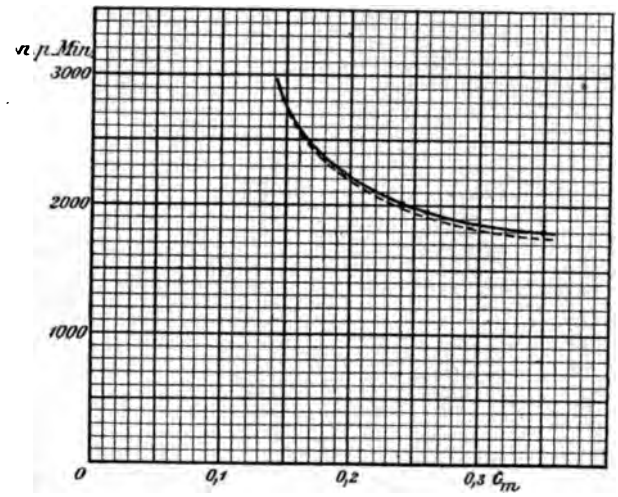



FIG. 102.

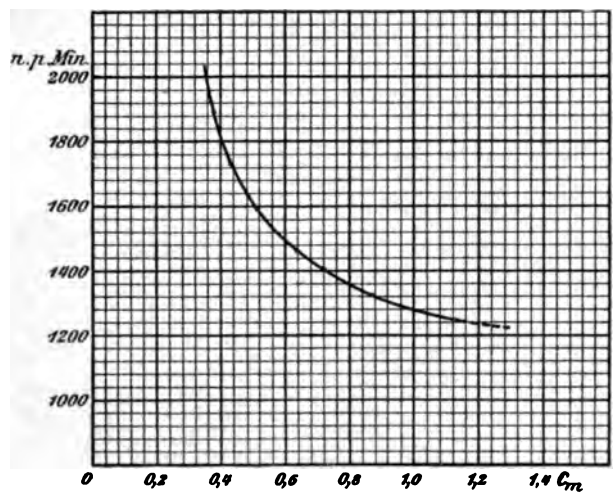



FIG. 103.

line by calculation from the magnetization curve of the same machine. The reason of the non-coincidence of these two lies in the fact that in taking the magnetization curve the machine was not

loaded, whilst the motor diagram was obtained with a consumption of a definite though comparatively small current—with a consequent voltage drop in the armature and an armature reaction.

Fig. 103 shows a similar curve from another machine. To bring the speed below the normal, the field coils of the machine were excited with about $1\frac{1}{2}$ times the normal exciting current.

It may be pointed out that we obtain different curves for ascending and descending magnetizing currents. In Fig. 102 both curves are for descending magnetization.

The determination of the no-load characteristic curve is important, as it discloses the behaviour of motors for variable speed. We can deduce from this experiment the size of the regulating resistance required and the speed limit before excessive sparking takes place. The characteristic curve of the motor under load is, however, of special practical importance, and this will be fully dealt with in a subsequent experiment.

## 2. Remarks on the Self-excitation of Shunt Generators

If a shunt machine is to self-excite, two conditions must be fulfilled, namely—

(1) The machine must have a trace of residual magnetism.

(2) The resistance of the shunt circuit must, at a given speed, not exceed a certain value, or with a given resistance of the shunt circuit the speed must not fall below a certain value.

The first of these conditions is almost invariably fulfilled. It seldom happens that complete demagnetization of the machine occurs. In such a case the magnetism is restored by passing a small current through the field coils from an external source (generally a number of cells). Simultaneously with the condition of residual magnetism, the second condition stated above must be fulfilled. For the better conception of this condition, let us refer to the no-load characteristic.

We found that in Experiment No. IV. a definite number of lines of force (N) is required to produce a certain E.M.F. To produce these lines of force a number of ampere-turns or, with a given number of turns on the field magnets, a certain exciting current $c_m$ is needed. We have seen further that the ratio between $c_m$ and the E.M.F. of a machine is not constant for all voltages, but is represented by a curve—the no-load characteristic. In Fig. 104 such a characteristic is drawn (see also Fig. 91) for a constant speed $n = 2000$. The field resistance of this machine $r_m = 360\omega$.

If, in Fig. 104, we plot the voltage required to send a current $c_m$ through the field, *i.e.* the voltage drop in the field winding as a function of the field current $c_m$, we get the straight line OA.

We will now assume the field winding to be directly connected to the armature terminals, and consider what takes place at an exciting current $c_m = 0{\cdot}6$. From the magnetization curve for $n = 2000$ and $c_m = 0{\cdot}6$, the armature voltage $= 244$. From the straight line for $r_m = 360$ and $c_m = 0{\cdot}6$, the voltage drop in the magnets $= 218$, *i.e.* 218 volts on the field terminals are required to maintain a current of 0·6 amp. in the field coils. As the latter are impressed with a voltage of 244, the exciting current will be larger than 0·6 amp., and

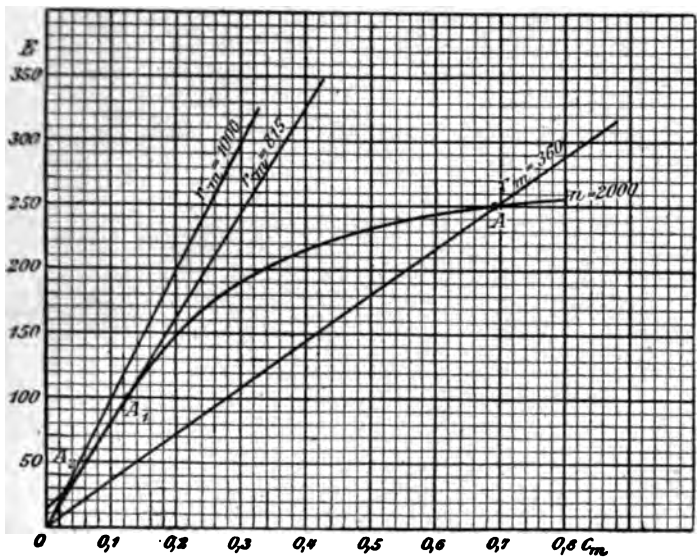



FIG. 104.

hence the voltage will rise to point A, the intersection of the straight line OA and the magnetization curve. At the point A the voltage drop in the field coils is equal to the armature voltage, and a stationary state is reached. We see from this that the voltage of a self-excited shunt machine at no-load is determined by the resistance of the shunt circuit, provided that the speed be constant.

If, with the same constant speed of the machine, we now increase the resistance of its shunt circuit—say, by inserting a shunt resistance —then the angle which the straight line representing the voltage drop makes with the abscissa will increase, and the point of intersection with the magnetization curve A will move to the left. Hence the

voltage which the armature will attain will be smaller. If the straight line coincides with the initial ascending branch of the magnetization curve (which branch, as we know, is nearly straight), then in our example the voltage drop in the field magnets would be equal to the armature voltage for all points between $c_m = 0$ and $c_m = 0{\cdot}12$; the armature voltage is therefore unsteady, and liable to assume any value between 0 and 100 volts ($A_1$). The machine is just on the point of exciting itself. By increasing the resistance of the shunt circuit by a small amount—say from 815 to 825ω—the straight line meets the magnetization curve at the origin, and the machine will fail to excite itself; since for any exciting current the voltage

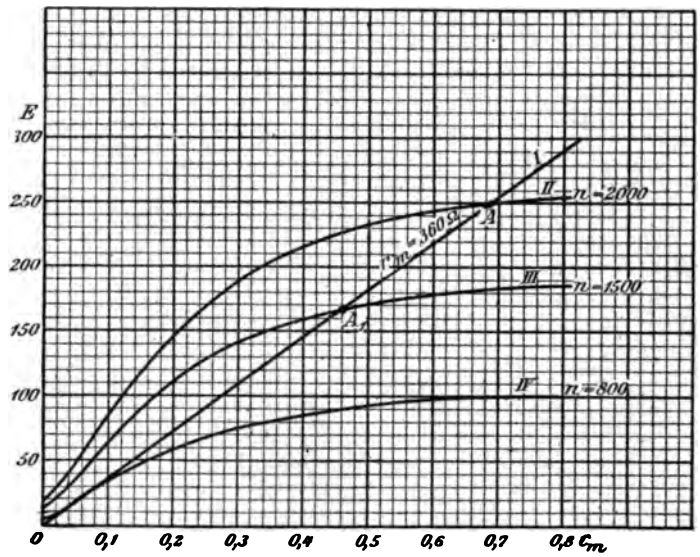



FIG. 105.

required for the field magnets will be greater than the armature voltage produced by this exciting current.

From these considerations it is evident that the cause of the non-excitation may be attributed to too large a resistance of the shunt circuit, which may either be due to too much regulating resistance or to several bad contacts.

Strictly speaking, the above conditions apply only to the case of no residual magnetism, *i.e.* when the magnetization curve goes through the origin. This is, however, very seldom the case, and generally the magnetization curve starts a little above the origin. The machine will therefore, even with a very large shunt resistance, attain a small

voltage. Even for $r_m = \infty$ the voltage would be equal to the residual voltage, and in Fig. 104 for $r_m = 1000\omega$, the voltage is about 32 ($A_2$).

It now only remains to show that with a constant resistance of the shunt circuit, the self-excitation of a machine depends on its speed. For this purpose, in Fig. 105 the magnetization curve of the same machine as before is drawn, but for three different speeds, namely, $n = 2000$ (normal), 1500, and 800. The field resistance ($r_m = 360\omega$) is constant throughout.

At $n = 2000$ the dynamo will excite itself, attaining, as before, a voltage of 250. If the speed is reduced to 1500, the machine will still excite itself, but the maximum voltage will be 170. With a further reduction of the speed to 800, the line I. no longer intersects the magnetization curve IV., and hence the machine cannot excite itself.

Thus the cause of non-excitation may also be found in too low a speed. Not only a reduction in speed, but also a displacement of the brushes from the neutral position causes the magnetization curve to be lower. As a matter of fact, a wrong brush position is a very frequent cause of the non-excitation. With any shunt dynamo a brush position can be found in which the machine will not excite itself.

The following is a recapitulation of the possible causes of non-excitation of shunt machines :—

(*a*) No trace of residual magnetism due to reverse magnetization. (Remedy: Exciting the machine from an external source, and thus creating a residual field.)

(*b*) Excessive resistance of the shunt circuit due to

(1) Too large a shunt resistance. (Remedy: Cutting out part of the resistance.)

(2) Break in winding.

(3) Bad brush contact (especially with carbon brushes). (Remedy: Grinding in the brushes.)

(4) Wrong connection of the field coils with each other or with the armature terminals.

(*c*) Speed too low.

(*d*) Wrong position of brushes.

## 3. The Series Machine

With a series machine the no-load characteristic can be determined with a separate excitation of the field, but this makes the experiment a little more difficult, inasmuch as a small voltage and a large current is required for the excitation of a series machine.

## Experiment No. IX

*No-load Characteristic of a Series Machine (Determination of the Relation between E.M.F. and Exciting Current at Constant Speed).*

DIAGRAM OF CONNECTIONS.

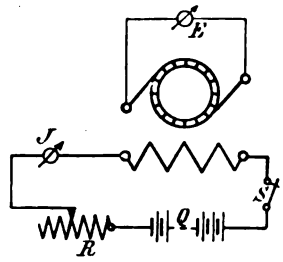



FIG. 106.

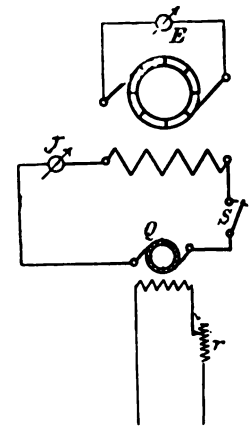



FIG. 107.

*Instruments and Apparatus required.*

E = Voltmeter (0 to about 40 per cent. above normal voltage of machine).
J = Ammeter (0 to about 50 per cent. above normal machine current).
R = Regulating resistance.
Q = Source of E.M.F.
One tachometer.

*Experiment.*—As stated above, a large current at a small voltage is required to excite a series machine, and for this purpose some accumulator cells of sufficient capacity may be employed (see Fig. 106), or a dynamo in series with a large resistance R. If a low voltage machine (as used for electro-chemical purposes) is available, it may be connected directly without a series resistance (see Fig. 107). The variation of the exciting current of the machine under test is then effected by regulating the voltage of the auxiliary machine by the shunt regulator *r* (the exciter being generally separately excited).

The experiment is performed as in experiment No. IV. Measure

the residual voltage with open shunt circuit, and after switching all the resistance R in circuit (Fig. 106), or reducing the voltage of the exciter to a minimum (Fig. 107), close switch S. Keeping the speed constant, increase gradually the exciting current, and record this and the corresponding armature voltage of the machine (E). When the maximum exciting current has been reached, the experiment should be repeated with descending magnetization, and finally the residual voltage should be measured again.

The results thus obtained should be plotted as in Experiment IV. Obviously the no-load characteristic of a series machine corresponds exactly to that of a shunt machine, hence a special example is unnecessary.

## 4. The Compound Machine

The no-load characteristic of a compound machine will correspond to that of a shunt machine, and to perform the experiment the machine may either be self- or separately excited. As, however, the shunt ampere-turns of a compound machine form only a part—though a large one—of the total ampere-turns, the machine will probably not attain a sufficiently high voltage with self-excitation. It is therefore better to excite the machine from a source, the E.M.F. of which is about 50 per cent. in excess of the normal machine voltage. If such a source is not available, a high excitation can be obtained by passing current through both the shunt and the series windings. The total ampere-turns are then equal to the sum of the series and shunt ampere-turns, provided that the windings assist one another. To check this proceed as follows: First pass a current through the shunt winding, run the machine, and observe the voltmeter. Then pass a current simultaneously through the series winding. If with the same speed as before the voltage has increased, then both windings act in the same direction. The diagram of connections for this experiment is a combination of the diagrams given for experiments Nos. IV. and IX.

# CHAPTER VII

## LOAD CHARACTERISTICS.

OUR considerations have hitherto been confined only to unloaded machines, *i.e.* machines through the armatures of which no (or a negligibly small) current was flowing during the experiment. In this chapter we will deal with characteristics of loaded machines; hence a few remarks may be made on the subject of voltage drop and armature reaction of continuous current machines.

With the flow of a current through the armature of a dynamo, a certain voltage drop arises in the winding; with motors this voltage

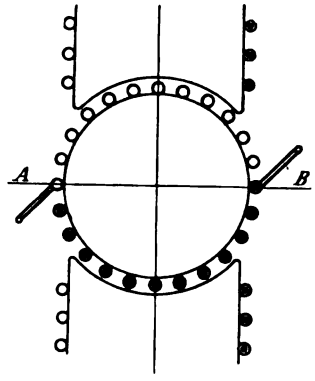



FIG. 108.

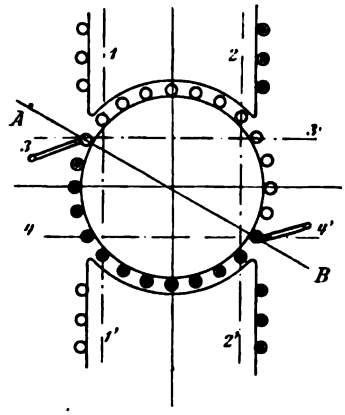



FIG. 109.

drop causes the E.M.F. to be smaller than the terminal voltage, with generators the terminal voltage to be smaller than the E.M.F. generated, thus involving a certain loss in either case. The amount of this voltage drop can directly be determined from the known armature resistance and the armature current.

The current flowing through the armature exerts also an influence on the field of the machine. The amount of this reaction is not

constant, but depends upon the strength of the armature current and the position of the brushes.

In Fig. 108 is shown the diagram of an armature through which current is flowing with the brushes in the neutral position. From this diagram we see clearly that the armature produces a field at right angles to the field produced by the field windings. These two fields produce a resultant, the direction of which depends on the strength of the armature current; hence the original homogeneous field is distorted and the neutral position displaced. Owing to the distortion of the field, the induction in the air-gap is altered; it will be increased in one part and decreased in another (see Fig. 110). With higher inductions the permeability decreases at a higher rate than the growth of the induction. Hence the action of the so-called cross ampere-turns will be to increase the resistance of the magnetic circuit of a machine, with the result that the induction or the total flux will decrease. This decrease of the total flux will be greater the larger the number of cross ampere-turns, *i.e.* the larger the load. Further, the magnetic resistance increases more rapidly the higher the saturation of the iron, *i.e.* the greater the excitation of the machine. Thus at a constant load the action of the cross ampere-turns increases with increasing excitation.

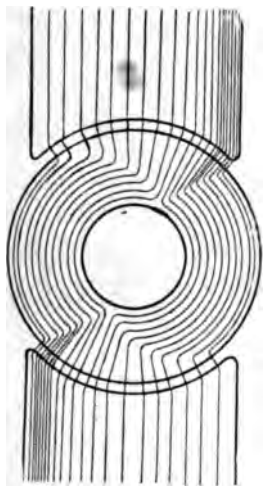


FIG. 110.

As explained above, the neutral position of a machine is shifted with the increase of load. The conditions of commutation are consequently altered, and for sparkless running of many machines a shifting of the brushes is necessary. In such cases the brushes of a generator must be shifted in the direction of rotation, and that of a motor against the direction of rotation. As soon, however, as the brushes are shifted from their previous position, the armature reaction is altered (see Fig. 109). The field produced by the armature has now the direction AB, and may be imagined to consist of two components, viz. a component perpendicular to the direction of the main magnetic field, and produced by the so-called cross ampere-turns lying between 1 1′ and 2 2′ (see Fig. 109) and a second component, produced by the windings between 3 3′ and 4 4′ having the same direction as the main magnetic field, but directly opposing the latter. Thus these "back ampere-turns" weaken the primary or main field. The action of these windings is obviously directly (or taking into account the

stray field nearly directly) proportional to the strength of the armature current, besides depending upon the brush position.

The cross and back ampere-turns form what is generally termed "the armature reaction." The influence of armature reaction on the working of generators and motors will be seen in the following experiments.

## 1. Shunt Generators

### Experiment No. X

*Load Characteristic of a separately excited Shunt Machine (Determination of the Relation between Exciting Current and Terminal Voltage of a Dynamo with Constant Load and Speed).*

DIAGRAM OF CONNECTIONS.

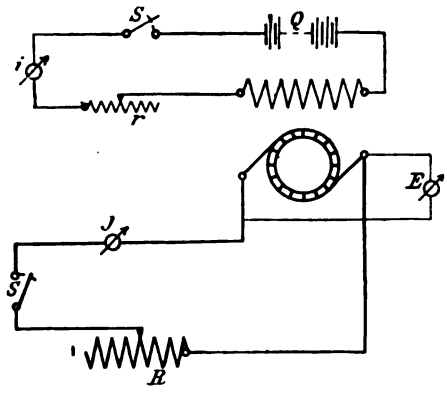



FIG. 111.

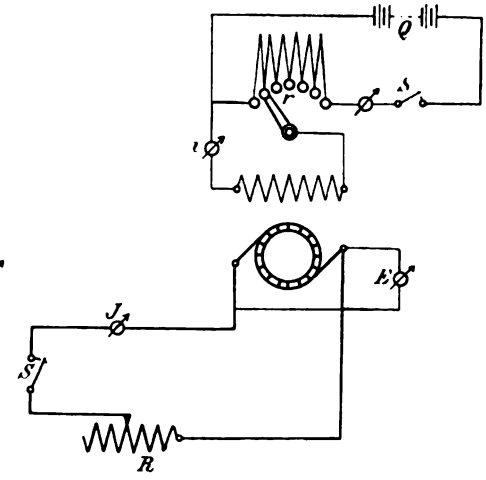



FIG. 112.

*Instruments and Apparatus required.*

E = Voltmeter (proportional scale from 0 to 25 per cent. above normal machine voltage).
J = Ammeter (about $\frac{1}{4}$–$\frac{5}{4}$ normal machine current).
R = Main resistance.
S = Main switch.
$r$ = Shunt regulator.
$i$ = Shunt ammeter.
Q = Source of E.M.F. for excitation of machine.
$s$ = Field switch.
One tachometer.

The machine to be tested may be driven either by a belt or directly by another electric motor. In either case, however, the speed must be kept constant. Should the auxiliary motor not be considerably larger than the machine, then the speed of the former will fall when the latter is loaded. Hence, to obtain a constant speed, it is necessary to insert a regulating resistance in the shunt circuit of the motor. By weakening the field the speed can be increased, and thus compensate for any drop of speed due to increasing load. The diagram of connections for the motor is the same as given in experiment No. VII.

*Experiment.*—Before performing the load experiment, a few points of the no-load characteristic should be determined (see Experiment No. IV.). Then open the field switch and close the main switch S. Start the machine and bring it to normal speed. The first series of readings should be taken with a small armature current, say about one-fourth of the normal. Hence, with the shunt circuit still broken, adjust the main resistance R so that the ammeter shows one-fourth of the normal current. In many cases the residual magnetism will be sufficient to produce this current in the armature if the latter is short-circuited, *i.e.* all the resistance R cut out. Should, however, the residual voltage be insufficient to produce this current, close the field switch and regulate the shunt current so as to obtain the required current in the armature. Record the armature voltage, armature current, exciting current, and check the speed. Then increase the exciting current by short-circuiting part of the shunt resistance, and reduce the main current (which has increased owing to the increased exciting current) to its former value, and, if necessary, regulate the speed. These regulations should as far as possible be made simultaneously. Repeat the experiment for a number of different exciting currents, keeping the main current and speed constant, and record the exciting current and armature voltage.

From this series of records the load characteristic can be obtained for a certain armature current (in our case for one-fourth of the normal). It is important also to know the characteristic for a number of other currents. Thus the experiment should be repeated for an armature current of say $\frac{1}{2}$, $\frac{3}{4}$, $\frac{4}{4}$, and $\frac{5}{4}$ of the normal. As we shall see later on, the position of brushes has an influence on the result of this experiment, and should therefore be the neutral throughout the experiment. The experiment should also be repeated with the normal current and with the brushes moved forward a few segments in the direction of rotation.

If the results are plotted, as in Fig. 113, we obtain the load characteristics for the respective load currents. Fig. 113 shows the no-load characteristic of a machine (curve I.) and three load characteristics, viz. for $C = \frac{1}{2}$ (II.), normal (III.), and $1\frac{1}{2}$ times the

normal current (IV.). From these curves it is seen that the load characteristics fall below the no-load curve, and the larger the load, *i.e.* the larger the armature current, the greater the fall. This can easily be explained from what we have said before: the current flowing through the armature causes a certain voltage drop, and the armature field weakens the main field, and consequently produces a further drop in the voltage. In Fig. 114 the no-load characteristic (I.) and the load characteristic for 15 amps. (IV.) have been plotted. If the armature

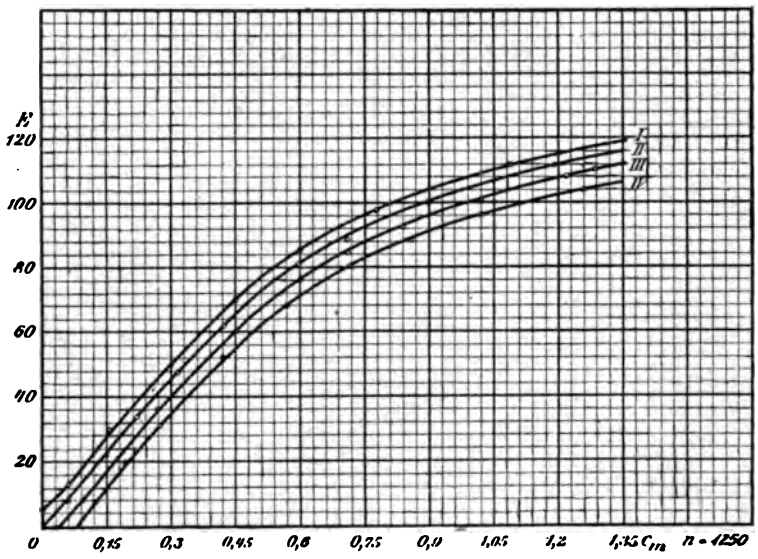



FIG. 113.

resistance $r_a$ is known, then the voltage drop in the armature is constant if the armature current is constant—

$$e = Cr_a$$

In our example C = 15, $r_a$ = 0·768; thus $e$ = 11·5 volts. If this voltage drop be plotted in Fig. 114 as a straight line II., and the ordinates of II. and IV. be added, we obtain another curve III. (shown dotted), which represents the E.M.F. of the loaded armature as a function of the exciting current. Since curve I. shows the E.M.F. of the unloaded armature as a function of the exciting current, the difference of ordinates of curves I. and III. shows for any exciting current the voltage drop caused by the armature reaction. In Fig. 114, $M_2M_3$ represents the ohmic voltage drop, $M_1M_2$ the drop due to

armature reaction. To compensate the total voltage drop, *i.e.* to bring the machine to the no-load voltage again, we must increase the exciting ampere-turns, and hence the exciting current. In our example $M_1N$ represents the current by which we must increase the exciting current in order that the voltage shall attain the value which it had at no-load.

The additional ampere-turns comprise the ampere-turns required for compensating the ohmic voltage drop and those required for compensating the drop due to armature reaction. As the former is constant for a constant armature current, the additional field required

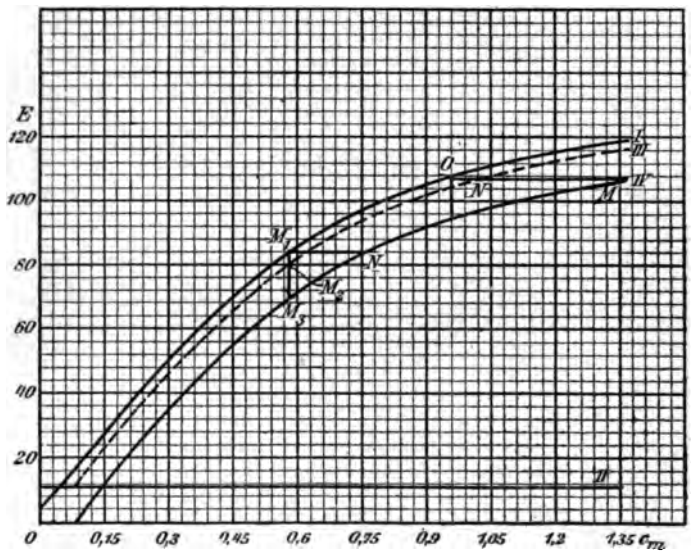



FIG. 114.

for its compensation is also constant. On the other hand, the permeability of the iron path decreases with increasing excitation, so that the ampere-turns necessary to produce this additional field are larger the greater the excitation. In Fig. 114 the line NM represents the ampere-turns (or the exciting current) necessary for the compensation of the ohmic voltage drop.

From the curves we see that with lower excitations (with lower inductions and nearly constant permeability) the additional ampere-turns are nearly constant, while with higher excitations (with rapidly decreasing permeability) these ampere-turns increase rapidly.

The armature reaction consists of the combined action of the cross and back ampere-turns. In Fig. 114 ON represents the

ampere-turns required for the compensation of the total armature reaction. With the brushes fixed in any position and with constant current, the number of demagnetizing ampere-turns, and hence also the ampere-turns necessary for their compensation, is constant. The effect of the cross magnetization is nearly zero for low excitation (induction), but grows rapidly with increasing excitation. The total ampere-turns required for compensating the armature reaction hence grow rapidly with increasing excitation (induction), which can be seen clearly from Fig. 114. As the number of demagnetizing ampere-turns becomes larger, the further the brushes require shifting from the neutral position, the total voltage drop will also be larger, and simultaneously the number of ampere-turns required for its compensation becomes greater. As an example, the curves of a 40 K.W. dynamo are given in Fig. 115. Curve I. represents the no-load characteristic, II. the load characteristic (C = 400 amps.); both curves have been obtained with the brushes in the neutral position. After the brushes have been moved the width of two commutator bars forward, the curve III. has been obtained, the load being again 400 amps. The voltage drop due to armature reaction is here very considerable.

Obviously a dynamo is better the smaller its voltage drop at a certain load. This voltage drop, even with separately excited machines, makes a regulation of the shunt current necessary. With self-excitation this regulation is still more essential. With load the terminal voltage decreases; hence the shunt current is reduced, which causes a further fall of the voltage. Thus with the same machine the total voltage drop will be larger with self- than with separate excitation (see also Experiment No. XII.).

The ohmic voltage drop depends on the resistance of the armature (the latter is comparatively smaller the larger the machine). The voltage drop due to armature reaction depends also upon the factors (including the brush position) mentioned above. With the brushes in the neutral position it is a minimum. Obviously a machine will be better with regard to constant voltage if a displacement of brushes with any load is not required.

The voltage drop has with success been reduced considerably, and with good modern machines is only a very small percentage of the normal voltage.

As discussed above, the shunt current of a dynamo must be regulated according to the load, if the terminal voltage is to be kept constant. The limits between which this regulation has to be made can be found from the load characteristics. Apart from the voltage drop, the difference in resistance of the field winding when hot and cold necessitates the insertion of an adjustable resistance in the shunt circuit of dynamos. The experimental determination of the exact size of such shunt regulators will be shown in Chapter XI.

## EXAMPLE X.

*Load Characteristic of a separately excited Shunt Dynamo.*

Machine, No. 12519. Type and maker, D101, Crompton & Co.

Voltage, 100; current, 10 amps; output, 1 B.H.P.; revolutions per minute, 1400.

Instruments used—Vulcan Shunt-ammeter, No. 5999; Weston Ammeter, No. 4214; Voltmeter, Weston, No. 3416.

### TABLE OF RESULTS.

| Exciting current. | Armature current. | Terminal pressure. | Speed. | Remarks. |
|---|---|---|---|---|
| 0·00 | 0 | 5·6 | 1250 | Residual field |
| 0·06 | ,, | 13·0 | ,, | |
| 0·12 | ,, | 23·0 | ,, | |
| 0·16 | ,, | 29·2 | ,, | |
| 0·30 | ,, | 51·0 | ,, | I. (C = 0) |
| 0·45 | ,, | 70·0 | ,, | |
| 0·60 | ,, | 85·0 | ,, | |
| 0·78 | ,, | 97·5 | ,, | |
| 1·09 | ,, | 112·0 | ,, | |
| 0·06 | 5 | 8·0 | ,, | |
| 0·15 | ,, | 23·0 | ,, | |
| 0·22 | ,, | 34·0 | ,, | |
| 0·31 | ,, | 48·0 | ,, | |
| 0·42 | ,, | 62·0 | ,, | II. (C = 5) |
| 0·60 | ,, | 80·0 | ,, | |
| 0·71 | ,, | 88·0 | ,, | |
| 0·90 | ,, | 100·0 | ,, | |
| 1·19 | ,, | 112·0 | ,, | |
| 0·09 | 10 | 8·0 | ,, | |
| 0·17 | ,, | 21·5 | ,, | |
| 0·27 | ,, | 36·0 | ,, | |
| 0·45 | ,, | 61·0 | ,, | |
| 0·60 | ,, | 76·0 | ,, | III. (C = 10) |
| 0·71 | ,, | 84·0 | ,, | |
| 0·84 | ,, | 92·0 | ,, | |
| 1·02 | ,, | 100·0 | ,, | |
| 1·22 | ,, | 108·0 | ,, | |
| 1·29 | ,, | 110·0 | ,, | |

TABLE OF RESULTS—*continued.*

| Exciting current. | Armature current. | Terminal pressure. | Speed. | Remarks. |
|---|---|---|---|---|
| 0·12 | 15 | 8·0 | 1250 | IV. (C = 15) |
| 0·19 | ,, | 20·0 | ,, | |
| 0·27 | ,, | 32·0 | ,, | |
| 0·42 | ,, | 52·0 | ,, | |
| 0·57 | ,, | 68·0 | ,, | |
| 0·72 | ,, | 80·0 | ,, | |
| 0·86 | ,, | 88·0 | ,, | |
| 1·02 | ,, | 96·0 | ,, | |
| 1·26 | ,, | 104·0 | ,, | |

NOTE.—Brushes in neutral position.

The results of this experiment are plotted in Fig. 113. This machine works with comparatively low inductions (see former experiment); thus the ampere-turns required to compensate the drop

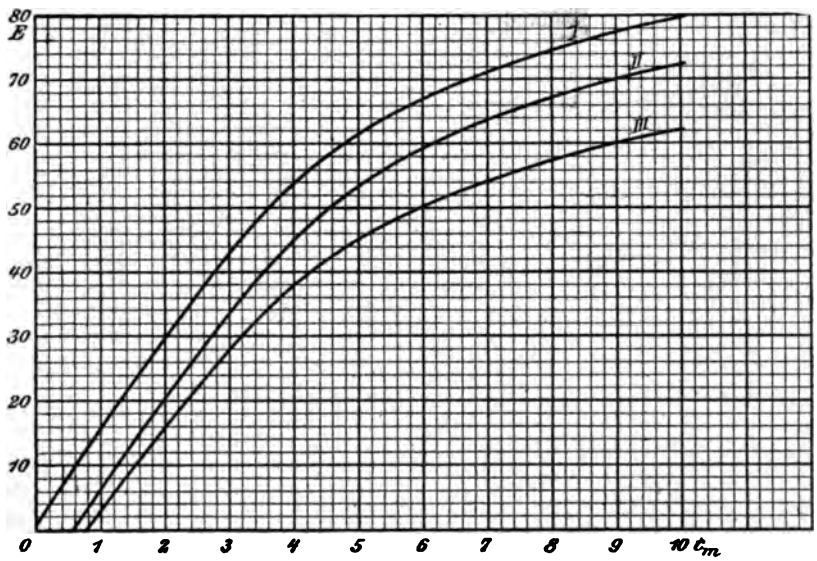



FIG. 115.

due to the armature reaction are small compared with that for compensating the ohmic drop.

Fig. 115 shows the corresponding characteristic of a 40 K.W. generator. The influence of the brush position on the voltage drop is exemplified in the diagram.

The above experiment could also be made with a self-excited machine, but in such a case it is very difficult (sometimes impossible) to get the lower part of the characteristic, otherwise there is no difference between these two experiments.

## Experiment No. XI

*External Characteristic of a separately excited Shunt Dynamo (Determination of the Relation between Terminal Voltage and Armature Current—Shunt Current and Speed Constant).*

DIAGRAM OF CONNECTIONS.

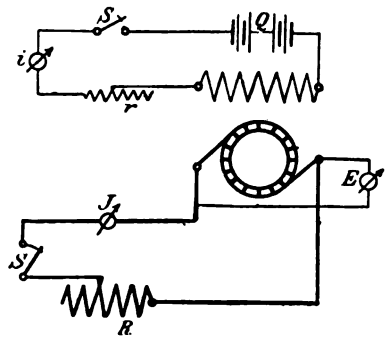



FIG. 116.

*Instruments and Apparatus required.*

E = Voltmeter (with open scale at about the normal voltage).
J = Ammeter (0 to about $1\frac{1}{2}$ times the normal current).
S = Main switch.
R = Regulating resistance.
*i* = Shunt ammeter.
*s* = Field switch.
*r* = Shunt regulator.
Q = Source of E.M.F.
One tachometer.

In this experiment the speed of the machine must be kept constant; thus for driving the dynamo, the same remarks apply as in Experiment No. X.

During the experiment the exciting current of the dynamo must be kept constant, and even if the voltage of Q were constant, the shunt current gradually decreases, owing to the increase of the field resistance due to increased temperature. Hence a regulating resistance R should be provided. If the field coils have reached their final temperature before commencing the experiment, the regulator can be omitted.

*Experiment.*—Start the set and bring it to normal speed. Then open switch S and close the field switch. By means of *r* adjust the dynamo voltage to normal. During the experiment keep the speed and shunt current constant.

Next close the main switch S, taking care that all the resistance R is in circuit. The ammeter J will indicate a small current, and the voltmeter a slight fall. Increase the dynamo load gradually by cutting out part of R, until the machine begins to spark. Take readings of the armature current and the corresponding armature voltages. For the first part of the curve only a few points are required, whereas more readings should be taken at the higher loads. If the speed of the driving motor falls, owing to the increased load, it must be regulated to the normal by weakening the field.

Throughout the experiment the brushes should be in the neutral position; if this is not possible, they must be gradually shifted with increasing load until sparking is eliminated.

As will be shown later on, the brush position has a great influence on the result of this experiment. Thus the latter should be performed with three different brush positions, viz.—

(1) With brushes in the neutral position.
(2) With brushes moved backwards (against direction of rotation).
(3) With brushes moved forwards (in the direction of rotation).

## Example XI.

*External Characteristic of a Self-excited Shunt Dynamo.*

Machine, No. 12519. Type and maker, D101, Crompton & Co.

Voltage, 100; current, 10 amps.; output, 1 B.H.P.; revolutions per minute, 1400.

Instruments used—Combined Weston Volt-ammeter, No. 1236; Weston Ammeter, No. 4214.

TABLE OF RESULTS.

| Speed. | Exciting current. | Main current. | Terminal voltage. |
|---|---|---|---|
| 1400 | 0·75 | 0 | 110 |
| ,, | ,, | 2 | 108 |
| ,, | ,, | 5 | 105 |
| ,, | ,, | 7 | 103 |
| ,, | ,, | 8 | 102 |
| ,, | ,, | 9 | 101 |
| ,, | ,, | 10 | 100 |
| ,, | ,, | 11 | 99 |
| ,, | ,, | 12 | 98 |

NOTE.—Brushes in neutral position.

The results of this experiment are plotted in Fig. 117 (Curve I.). From the diagram we see that, notwithstanding the constant speed and

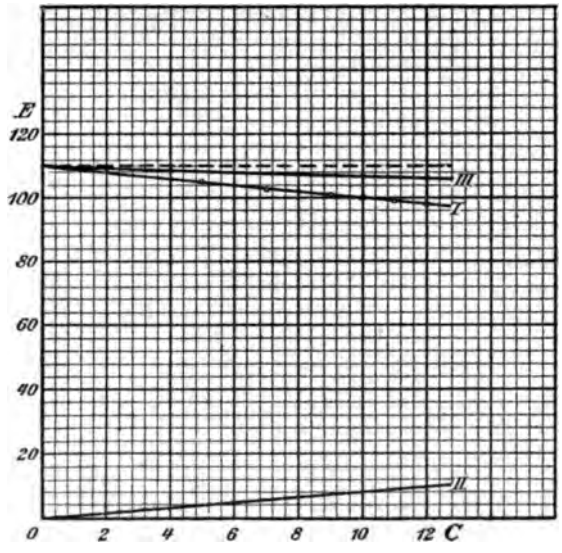



FIG. 117.

excitation, the terminal voltage falls with increasing load. The reason of this is obvious. The current flowing through the armature produces

a magnetic field which weakens the main field. In consequence of the weakened field, the E.M.F. induced in the armature decreases, and further, owing to the ohmic voltage drop with load, the terminal voltage is smaller than the E.M.F. induced. Each individual drop (armature reaction and ohmic drop) increases with the load.

It is desirable to know the value of each individually. The armature resistance must hence be known, and is determined by any of the methods described in Chapter II. In Fig. 117 the ohmic voltage drop in the armature is plotted against the armature current (Curve II.). (This curve bends slightly downwards on account of the resistance decreasing with increasing current.) Adding the

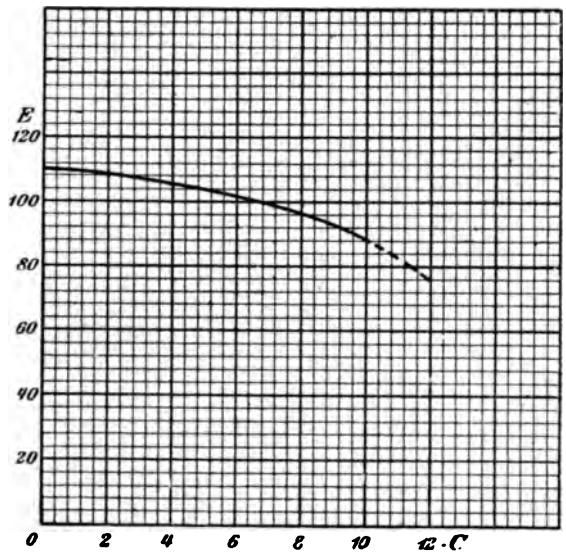



FIG. 118.

ordinates of Curves I. and II., we get the Curve III., representing the E.M.F. of the armature as a function of the armature current. This curve is called the "internal characteristic," and shows clearly the influence of the armature reaction on the voltage drop. From this diagram we see that the voltage drop due to armature reaction is with this machine not very large compared with the ohmic voltage drop. Whereas the latter is independent of the brush position, the former increases rapidly with the movement of the brushes forward. The effect of shifting the brushes is very marked in Fig. 118. This curve (terminal voltage as a function of the main current) was obtained by moving the brushes of the above machine forward.

The internal characteristic is important for judging a machine. As a rule, a machine will be better the smaller its total voltage drop with increasing load. Though in some cases a large voltage drop is not of great disadvantage—as, for instance, in the case of a pure power transmission—yet in the majority of cases, especially with machines for lighting purposes, a variation in voltage of more than ± 3 per cent. is not permissible. As with some machines (especially with smaller ones) the voltage drop between full and no-load considerably exceeds this value, a regulation of the shunt current becomes necessary, even with separately excited machines. The limits between which this regulation has to take place and the number of steps of the shunt regulator will be smaller the smaller the total voltage drop. We shall see in the next experiment that the effect of the voltage drop is considerably greater with self-excited than with separately excited machines.

Since the armature reaction increases when the brushes are moved from the neutral position, a machine will be best if the brushes can be left in the neutral position for all loads.

The effect of the armature reaction depends also on the ratio of the strength of the main primary field to that of the armature field. The smaller the main field is, compared with the latter, the larger will the total voltage drop be. It follows therefore, that the voltage drop will be larger with a machine working with a weakened field and an increased speed than if the field was strengthened and the speed decreased.

We have hitherto assumed that the primary field is weakened by the armature field; this, as a matter of fact, is the case when the brushes of a dynamo are moved forwards in the direction of rotation. If the brushes be moved against the direction of rotation, the main field is strengthened by the armature field. Hence the E.M.F. induced in the armature would increase with increasing load. On the other hand, the ohmic resistance causes the terminal voltage to be smaller than the E.M.F. generated.

The terminal voltage will therefore rise or fall with increasing load, according as the former increase of pressure or the latter ohmic drop preponderates; and if both are equal, the terminal voltage will remain constant at all loads. Since, by altering the brush position, the amount of the armature reaction can be varied at will, we have here a *theoretical* means of compounding a dynamo, namely, a means of keeping a constant terminal voltage at all loads without regulation of the shunt current.

In practice, it is very seldom possible to shift the brushes of a dynamo against the direction of rotation, as this would with most machines affect the conditions of commutation, giving rise to heavy sparking. The above is therefore of theoretical value only, and it

can be made use of with machines having very good sparking constants, *i.e.* possessing a small reactance voltage only.

However, it is sometimes interesting to find the external charac-

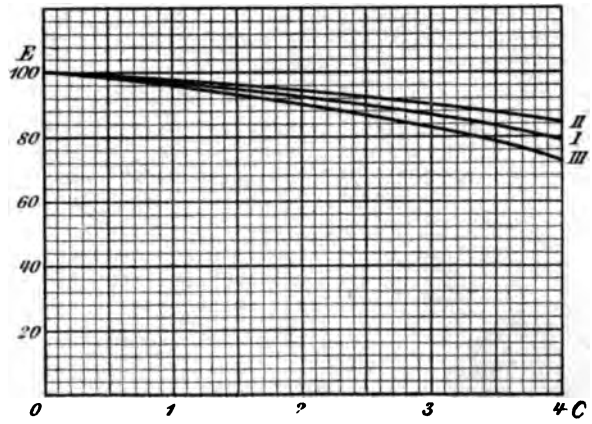



FIG. 119.

teristic of a machine with the brushes shifted against the direction of rotation. The results of such an experiment are shown in Fig. 119.

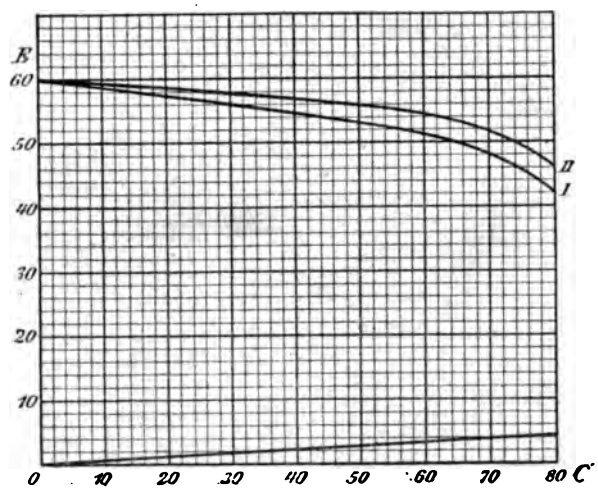



FIG. 120.

The machine employed for this experiment was a small Schuckert dynamo. Curve I. has been obtained with the brushes in the neutral

position. The brushes were then moved one and a half commutator bars backwards, and to get the same no-load voltage the exciting current was slightly increased. This gave Curve II. Finally, Curve III. was obtained with the brushes shifted in the direction of rotation.

In Fig. 120 the external (I.) and internal (II.) characteristics are given for a machine in which the drop due to armature reaction considerably exceeds the ohmic voltage drop. Here the rapid fall of the terminal voltage at a small overload is characteristic (normal load, 60 amps.). From the internal characteristic we see that up to a certain current (about 50 amps.) the armature reaction is nearly

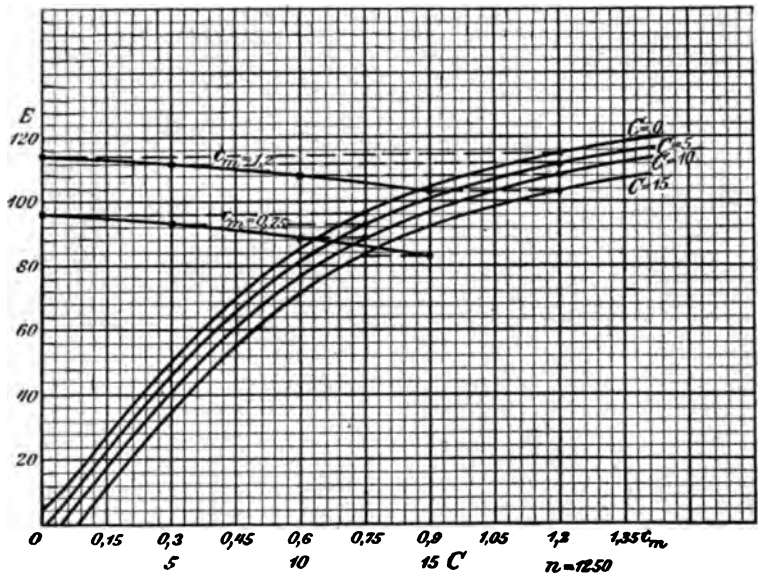



FIG. 121

proportional to the load. Beyond this current the E.M.F. falls at a greater rate (the weakening of the main field due to the armature field is here very considerable).

The external characteristic of a shunt machine may also be obtained as follows: The machine is fully loaded (or overloaded) and brought to its normal voltage, and then the load is thrown off gradually (speed and exciting current remaining constant). With decreasing load the voltage will obviously rise. The armature currents and corresponding voltages are recorded for all loads. There is no perceptible difference in the results obtained in the two

methods of performing the experiment, provided that the percentage voltage drop of the machine is not excessive.

Finally, it may be mentioned that the external characteristic of a shunt machine can be found graphically from the load characteristics. For this purpose at least two to three load characteristics must be given. The construction of the curves is shown in Fig. 121, and needs no further explanation.

## Experiment No. XII

*External Characteristic of a self-excited Shunt Dynamo (Determination of Relation between Armature Current and Terminal Voltage of a self-excited Shunt Dynamo).*

DIAGRAM OF CONNECTIONS.

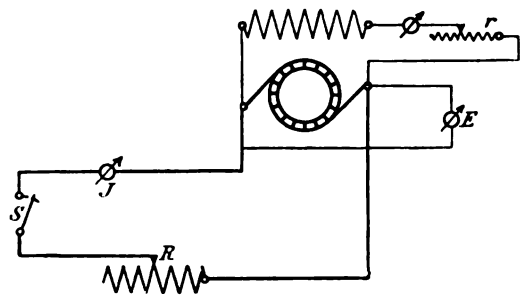



FIG. 122.

*Instruments and Apparatus.*

E = Voltmeter (0–25 per cent. above normal voltage).
J = Ammeter (0 to $1\frac{1}{2}$–$2\frac{1}{2}$ times normal current).
R = Main resistance.
S = Main switch.
One tachometer.
(With regard to the auxiliary motor, see Experiment No. X.)

*Experiment.*—The method of performing this experiment is quite similar to the previous experiment, the only difference being the connections of the field winding (which in the present experiment is connected to the armature terminals), and that the shunt resistance is unaltered during the experiment. After the machine has been brought to its normal speed (which must be kept constant during the experiment), read the no-load voltage with switch S open. Then

close the main circuit, inserting first the whole resistance R, so that the main current is small. Take readings of the main current and voltage. Then decrease R, *i.e.* increase the armature current gradually, when the terminal voltage will fall. As R is gradually decreased, a point will be reached when the armature current will no longer increase, but fall, and if finally the machine is short-circuited (R = 0), we get—at a terminal voltage = 0—a definite armature current.

The brushes should, if possible, not be moved during the experiment. The same experiment should be repeated with the brushes shifted in the direction of rotation.

As stated above, the shunt resistance should not be altered during the experiment. If the voltage at no-load is considerably in excess of the normal voltage, it should be reduced to the latter by means of the shunt resistance. The voltage at no-load may also be adjusted to the normal voltage + voltage drop at full load.

## Example XII.

*External Characteristics of a self-excited Shunt Dynamo.*

Machine, No. 12519. Type and maker, Crompton & Co.

Voltage, 100; current, 10 amps.; output, 1 B.H.P.; revolutions per minute, 1400; number of poles, 2.

Instruments used—Combined Weston Volt-ammeter.

Table of Results.

| Speed. | Armature current. | Terminal voltage. | Remarks. |
|---|---|---|---|
| 1400 | 0 | 103·3 | Brushes in the neutral position |
| ,, | 8 | 93 | |
| ,, | 12 | 83 | |
| ,, | 14 | 78 | |
| ,, | 16 | 72 | |
| ,, | 18 | 64 | |
| ,, | 19·8 | 44 | |
| ,, | 19·2 | 32 | |
| ,, | 18 | 25 | |
| ,, | 16 | 17 | |
| ,, | 5·7 | 0 | |

Plotting the main current as abscissæ and the corresponding voltages as ordinates, we get the curve shown in Fig. 123, from which the characteristic behaviour of a shunt machine becomes very clear, and the curve is therefore frequently termed the "characteristic" of a shunt dynamo.

From this curve we see that the voltage of the dynamo falls with increasing load. Comparing this drop of voltage with that of the separately excited machine for the same current (see Fig. 117), we find that it is considerably larger in the self-excited machine. This is obvious—with the separately excited machine the excitation was

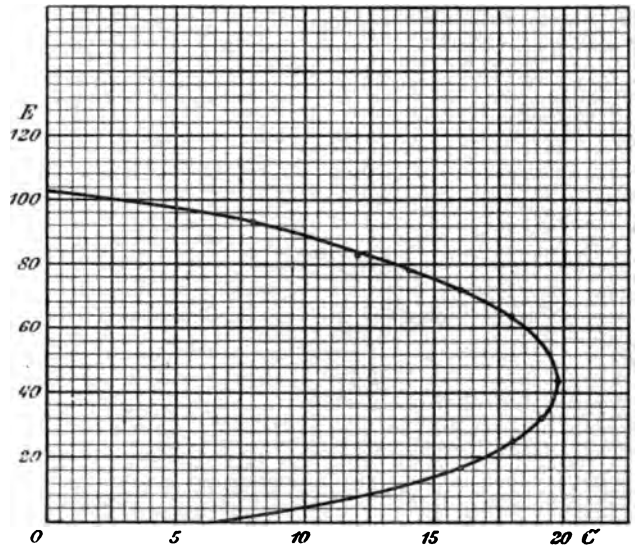



FIG. 123.

independent of the load, viz. constant. With the self-excited machine we have a drop due to ohmic resistance of the armature and a drop due to armature reaction; and since the field windings are connected with the armature terminals and their resistance is constant, the exciting current will decrease owing to the decreased voltage. This will cause a further drop of E.M.F., and hence terminal voltage. This goes on until a state of balance is reached.

If the load is continuously increased, and a certain current reached, the voltage will begin to fall rapidly. By further diminishing the main resistance, the current will remain practically constant for a short period. This constant current is called the "critical current." The curve then acquires a bend, and by decreasing the

main resistance further, the current *decreases* on account of the rapidly diminishing voltage. It should be observed that with the armature short-circuited (E = 0) the current is not zero, but has a certain value.

The characteristic thus obtained is very instructive with reference to the working of a shunt dynamo. We learn from it that a short-circuited machine loses its voltage. A sudden short circuit will hence scarcely damage the machine. But if the load of a shunt machine is gradually increased until the latter is short-circuited, then the machine may be more or less damaged, or even burnt out, according to the time elapsing between the normal load and the

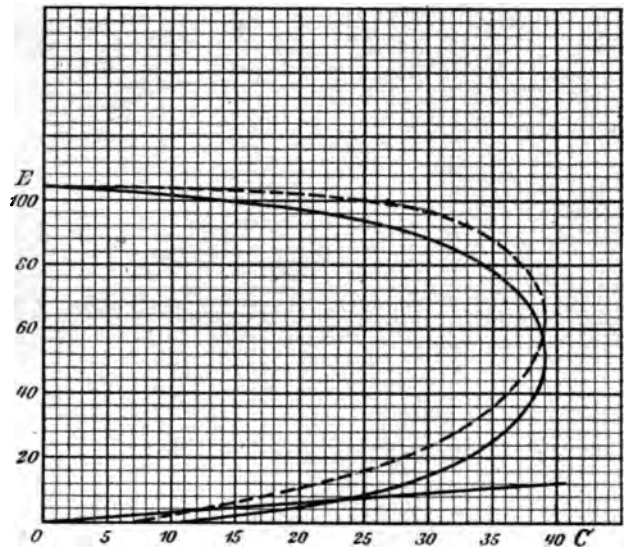



FIG. 124.

short circuit, and according to the ratio of the critical current to the normal working current.

Though the above property of the shunt dynamo is certainly advantageous, it should, however, not be taxed too far. The machine, the characteristic of which is given in Fig. 123, loses its voltage at a current of about 100 per cent. above normal. This complete loss of voltage may sometimes cause a great deal of trouble.

From our discussion of the influence of the brush position on the voltage drop, it is evident that the critical current of a machine will be smaller with the brushes shifted in, and larger with the brushes shifted against the direction of rotation.

In Fig. 123, for R = 0 (*i.e.* for short-circuited armature), C =

about 6 amps. If there were no residual magnetism, C would be zero. The residual voltage produces in the circuit, consisting of the armature and the ammeter (with cables), a current C. From C and the resistance of armature + ammeter, the residual voltage may be found.

In the last experiment we have seen that, with the armature resistance known we can find the internal from the external characteristic. This of course applies equally well to a self-excited machine. An example is given in Fig. 124.

The experiment described can evidently be only performed with such machines whose critical current is comparatively small. Where this is not the case, the experiment can only partly be performed. The "characteristic" can also be constructed from the no-load and two or three load characteristics.

## 2. Shunt Motors

### Experiment No. XIII

*Load Characteristic of a Shunt Motor (Relation between Speed and Load of a Shunt Motor—Terminal Voltage and Excitation constant).*

DIAGRAM OF CONNECTIONS.

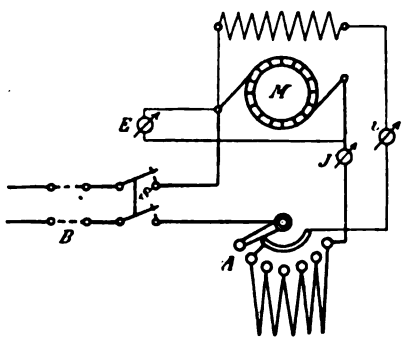



FIG. 125.

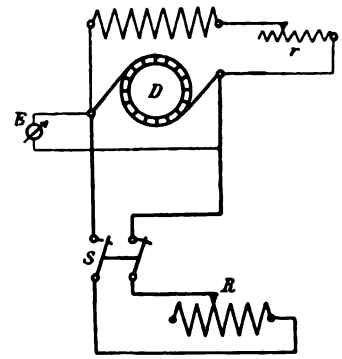



FIG. 125A.

*Instruments and Apparatus.*

E = Voltmeter (normal motor voltage).
J = Ammeter (0–25 per cent. above normal current).
A = Motor starter.
S = Main switch.
B = Fuse.
One tachometer.

The motor may be loaded either by a brake or by driving another machine which is loaded as a dynamo. The latter is preferable, as it is easier to maintain a constant load, and thus to obtain constant readings.

The dynamo must work on a variable resistance load, as shown in the diagram of Fig. 125A. When the load is adjusted, the main resistance gives a rough and the shunt resistance a fine adjustment.

*Experiment.*—Make sure that the starter (A) is in the "off" position before closing switch S. Start the motor light, with the dynamo and motor uncoupled. Read the terminal voltage, armature current, and speed. The current absorbed is called the no-load current. Then stop the motor, and couple it to the dynamo. Start the motor, and run up to speed—with the dynamo on open circuit. Take readings of the terminal voltage, armature current, and measure the speed. Now close the dynamo circuit, and by cutting out R increase the load (the fine adjustment being obtained by $r$).

Throughout the experiment keep the terminal voltage constant, and for various motor currents—$\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{1}{1}$, and $\frac{5}{4}$ normal—measure the corresponding speeds, and read the terminal voltage.

Record the results as below.

## Example XIII.

*Load Characteristic of a Shunt Motor.*

Machine, No. 35790. Type and maker, Bergman.

Voltage, 220; current, 6·15 amps.; output, $1\frac{1}{4}$ B.H.P.; revolutions per minute, 200; number of poles, 4.

Instruments used—Century set.

Table of Results.

| Terminal voltage. | Armature current. | Speed. | Corrected speed. | Remarks. |
|---|---|---|---|---|
| 220 | 3·0 | 1825 | 1825 | |
| 218 | 4·4 | 1780 | 1800 | |
| 220 | 5·55 | 1760 | 1760 | Brushes in the neutral position |
| 220 | 7·0 | 1710 | 1710 | |
| 221 | 8·45 | 1680 | 1670 | |
| 220 | 9·8 | 1600 | 1600 | |
| 220 | 10·4 | 1580 | 1580 | |

From the results of this experiment, plotted in Fig. 126, we see that the speed of a shunt motor decreases with increasing load. There are two causes influencing the variation in speed—firstly, the voltage drop in the armature, and secondly, the weakened field due to armature reaction. In the case of shunt generators, these two causes assist in lowering the terminal voltage, but in shunt motors the ohmic voltage drop produces a fall in speed proportional to the load, and the armature reaction an increase on account of the weakened field. With smaller loads the increase in speed is nearly proportional to the load, but somewhat greater with the higher loads.

Hence we see that the two effects—armature reaction and ohmic

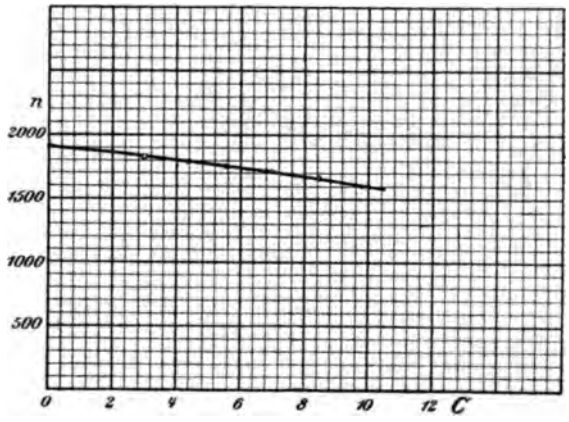



FIG. 126.

voltage drop—in the case of shunt motors oppose each other, and if the effects of both are equal, the speed will remain constant at all loads. If the effect of armature reaction preponderates, the speed will rise with increasing load, whereas it will fall should the effect of ohmic drop preponderate. In most cases met with in practice, the effect of ohmic voltage drop exceeds that of armature reaction, and hence the speed decreases with increasing load.

Let us now examine the influence of the field strength on the increase of speed (*i.e.* due to armature reaction). In Fig. 127 Curve I. is the load characteristic of a motor with normal excitation. The drop in speed between no-load and full load with this motor is not very great. By weakening the field and performing the same experiment we obtain Curve II. The speed from this curve is seen to *increase* with increasing load. This increase is due to the effect of

the armature reaction being greater with a smaller excitation (*i.e.* with a smaller induction in the iron).

By repeating the experiment with an exciting current greater than the normal, we obtain Curve III. The drop in speed between no-load and full load is larger than with normal excitation. With larger excitation (*i.e.* with larger inductions), the effect of the armature reaction is small, the ohmic drop thus preponderating.

Finally, let us discuss the influence of the brush position on the variation of speed of a shunt motor. Obviously, moving the brushes against the direction of rotation will increase the armature reaction, this increase being sometimes very considerable. In this way the influence of the voltage drop would be partly compensated. In Fig. 128 Curve I. represents the load characteristic of a 2 B.H.P. motor—with the brushes in the neutral position. In a second experiment (see Curve II.) the brushes were shifted against the direction

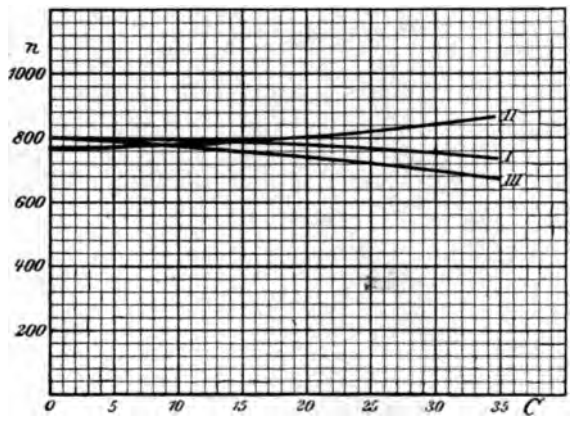



FIG. 127.

of rotation as the load increased. It will be seen from the diagram that in the second experiment the total fall in speed was smaller than in the first case.

From these experiments we gather that theoretically there is a brush position (depending upon the strength of excitation) at which the speed remains constant, or nearly so, for all loads. Nearly, because the armature reaction does not increase proportionally with the armature current.

With regard to the manner of performing the experiment, we may add that the exciting current should throughout remain perfectly constant, and the armature resistance should not vary. Hence,

prior to the experiment, the machine should run for some time with full load, until the armature and field coils have reached their maximum temperature. Where this is impossible, a small shunt resistance and shunt ammeter should be provided. At the beginning of the experiment as much shunt resistance must be inserted as the increase of the field coil resistance due to overheating is likely to be. By gradually cutting out the shunt resistance the field current can be kept constant.

The experiment may also be performed in the reverse order, namely, the motor loaded or overloaded to a certain extent, the speed regulated to normal by means of a small shunt regulator, and thence the load on the motor gradually decreased. The increase in speed thus obtained will generally be equal to the fall of speed when the

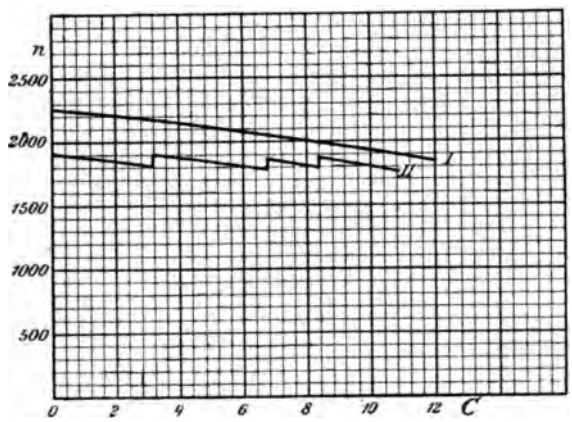



FIG. 128.

motor is loaded from zero to full load, provided that the percentage variation of speed is not excessive.

With well-built shunt motors the drop of speed between no-load and full load is not considerable, and the higher the efficiency of a motor the smaller will its drop of speed be. Again, the drop of speed will be smaller if the brushes are shifted backwards with increasing load. But one of the first conditions for a good motor is working at all loads with fixed brushes. This condition obviously makes a constant speed difficult.

When an absolutely constant speed at all loads is required, a shunt regulator must be added. The determination of the resistance of such a regulator will be dealt with in Chapter XI. An automatic regulation of the speed could of course be effected by a compound

winding, which would have to strengthen or weaken the field according as the speed of the shunt motor rises or falls with increasing load. As, however, the armature reaction is not quite proportional to the load, an absolute constant speed could not even then be obtained. This means of keeping the speed constant is hardly ever used.

## Experiment No. XIV

*Speed Characteristic of a Loaded Shunt Motor (Relation between Exciting Current and Speed of a Shunt Motor—Terminal Voltage and Load Constant).*

DIAGRAM OF CONNECTIONS.

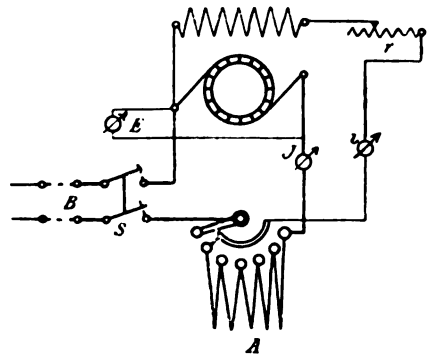



FIG. 129.

*Instruments and Apparatus.*

E = Voltmeter for normal motor voltage.
J = Ammeter (0–50 per cent. overload).
$i$ = Shunt ammeter.
A = Motor starter.
S = Main switch.
One tachometer.

For loading the motor, see p. 122. The diagram of connections for the dynamo as load is given in Fig. 125A.

*Experiment.*—After closing S see that all shunt resistance is short-circuited, *i.e.* that the exciting current is a maximum. Then

start the motor, regulating its armature current to about one-fourth of the normal (the brushes being in the neutral position). The armature current must be kept constant during the course of the experiment. Read the terminal voltage (E), the exciting current, the main current, and the speed simultaneously. Reduce the exciting current by inserting resistance in the shunt circuit, with the result that the speed rises. As a consequence of this, the load of both the dynamo and motor increases, and in order to keep the motor current constant, the dynamo current must be regulated by the main or the shunt regulator, or by both simultaneously.

When, with the higher speed, the motor current has been regulated again to one-fourth normal, read the terminal voltage and exciting current, and measure the speed. Then repeat the experiment by gradually reducing the motor exciting current (keeping its armature current constant). If possible, the brushes should not be shifted during the experiment. With reference to the upper limit of speed, see p. 92. The speed of a loaded motor will usually be limited not by the peripheral speed, but by its sparking, and the speed should be increased until the brushes commence to spark badly.

Repeat the experiment with a motor load of one-half normal, starting again with the normal speed. Reduce the shunt current gradually, and take a set of readings as before. As it is hardly to be expected that a machine will run at all loads and variable speed with the brushes in a fixed position, the latter should be shifted somewhat, prior to taking the second set of readings.

Repeat the experiment for three- and five-fourths of the normal motor current, and before each set of readings move the brushes a little, until finally the maximum displacement of brushes is reached. Notwithstanding, the maximum speed obtained without considerable sparking will be smaller the larger the load.

The results should be recorded as follows:—

## Example XIV.

*Speed Characteristic of a Loaded Shunt Motor.*

Machine, No. 4739. Type and maker, M6/5, Electro-Motor Co.

Voltage, 220; current, 15 amps.; output, 3 B.H.P.; revolutions per minute, 1400; number of poles, 4.

Instruments used—Century set.

TABLE OF RESULTS.

| Voltage. | Exciting current. | Speed. | Armature current. | Remarks. |
|---|---|---|---|---|
| 200 | 0·7 | 1500 | 3 | Curve V. |
| " | 0·6 | 1590 | 3 | |
| " | 0·5 | 1700 | 3 | |
| " | 0·4 | 1870 | 3 | |
| " | 0·7 | 1460 | 8 | Curve IV. |
| " | 0·6 | 1550 | 8 | |
| " | 0·5 | 1670 | 8 | |
| " | 0·4 | 1845 | 8 | |
| " | 0·7 | 1420 | 12 | Curve III. |
| " | 0·6 | 1520 | 12 | |
| " | 0·5 | 1640 | 12 | |
| " | 0·4 | 1820 | 12 | |
| " | 0·7 | 1375 | 15 | Curve II. |
| " | 0·6 | 1475 | 15 | |
| " | 0·5 | 1605 | 15 | |
| " | 0·4 | 1795 | 15 | |
| " | 0·7 | 1330 | 18 | Curve I. |
| " | 0·6 | 1440 | 18 | |
| " | 0·5 | 1565 | 18 | |
| " | 0·4 | 1765 | 18 | |

The results of this experiment are plotted in Fig. 130 (Curves I.–V.). The experiment in principle is the same as Experiment No. VIII., but in the latter experiment the motor runs light, whereas in this experiment it is under load. Thus the load characteristic for the same motor will generally lie below the no-load characteristic. As in the case of a dynamo, we can obtain the external characteristic of a motor from a number of its load characteristics. In the example given above, the external characteristic for $C_m = 0{\cdot}7$ would be—

$$\begin{array}{lll} C = 3 & n = 1500 & \text{(V.)} \\ C = 8 & n = 1460 & \text{(IV.)} \\ C = 12 & n = 1420 & \text{(III.)} \\ C = 15 & n = 1375 & \text{(II.)} \\ C = 18 & n = 1330 & \text{(I.)} \end{array}$$

*i.e.* the speed drops from 1500 at no-load to 1330 revolutions per minute at C = 18.

With a smaller exciting current, the drop in speed between no-load and full load is smaller, as with the lower induction a greater armature reaction and consequently a smaller rate of speed drop are produced.

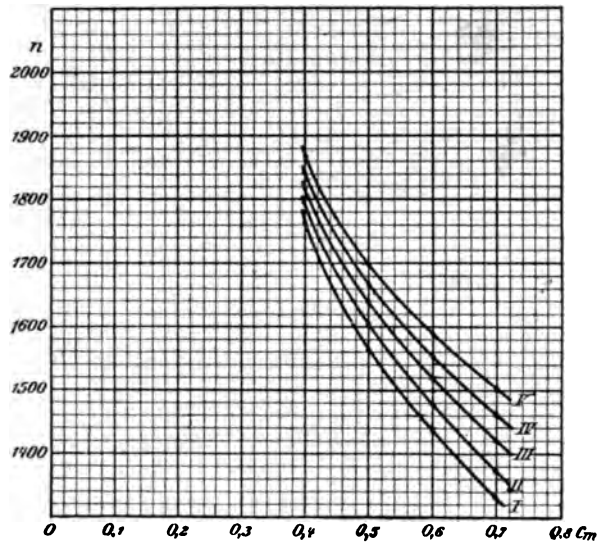



FIG. 130.

For instance, the external characteristic for $C_m = 0{\cdot}4$ is given by by the following:—

| | |
|---|---|
| C = 3 | $n = 1870$ |
| C = 8 | $n = 1845$ |
| C = 12 | $n = 1820$ |
| C = 15 | $n = 1795$ |
| C = 18 | $n = 1765$ |

*i.e.* the speed drops from 1870 to 1765. For $C_m = 0{\cdot}7$ the drop was about 13 per cent., but only 6 per cent. for $C_m = 0{\cdot}4$.

## 3. Series Generators

### Experiment No. XV

*External Characteristic of a Series Generator (Relation between Load and Terminal Voltage of a Series Generator—Speed constant).*

DIAGRAM OF CONNECTIONS.

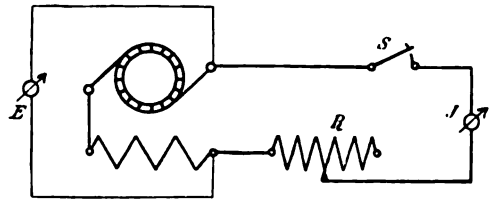



FIG. 131.

*Instruments and Apparatus required.*

E = Voltmeter for about $1\frac{1}{2}$ normal voltage.
J = Ammeter (about $1\frac{1}{2}$ normal current).
R = Main resistance.
S = Main switch.
One tachometer.
See p. 104 with reference to the auxiliary motor and connections.

*Experiment.*—Open S and bring the dynamo up to normal speed, which should be kept constant throughout the experiment. With switch S open, take the voltmeter reading due to residual magnetism, then close S, making sure that all resistance R is in circuit. By gradually short-circuiting part of the main resistance, the voltage of the dynamo will increase; then, for a number of different currents (about $\frac{1}{8}$, $\frac{1}{4}$, etc., to about $1\frac{1}{2}$ normal), read the corresponding terminal voltages. During these readings the brushes should not be moved. Another series of readings should be taken with the brushes shifted in the direction of rotation.

EXAMPLE XV.

*External Characteristic of a Series Generator.*

Machine, No. 3475. Type and maker, Parker.

Voltage, 200; current, 15; output, 3 K.W.; revolutions per minute, 1000.

Instruments used—Weston Volt-ammeter.

TABLE OF RESULTS.

| Speed. | Terminal voltage. | Current. | Remarks. |
|---|---|---|---|
| 800 | 60 | 2·0 | Brushes in the neutral position (I.) |
| ,, | 115 | 4·0 | |
| ,, | 170 | 7·0 | |
| ,, | 210 | 11·2 | |
| ,, | 215 | 14·0 | |
| ,, | 210 | 17·5 | |
| ,, | 200 | 21·8 | |
| ,, | 190 | 24·0 | |
| ,, | 128 | 5·0 | Brushes gradually shifted (II.) |
| ,, | 197 | 10·0 | |
| ,, | 209 | 15·0 | |
| ,, | 196 | 20·0 | |
| ,, | 180 | 23·5 | |
| ,, | 127 | 5·0 | Brushes shifted two and a half bars (III.) |
| ,, | 192 | 10·0 | |
| ,, | 204 | 15·0 | |
| ,, | 192 | 20·0 | |
| ,, | 183 | 22·5 | |

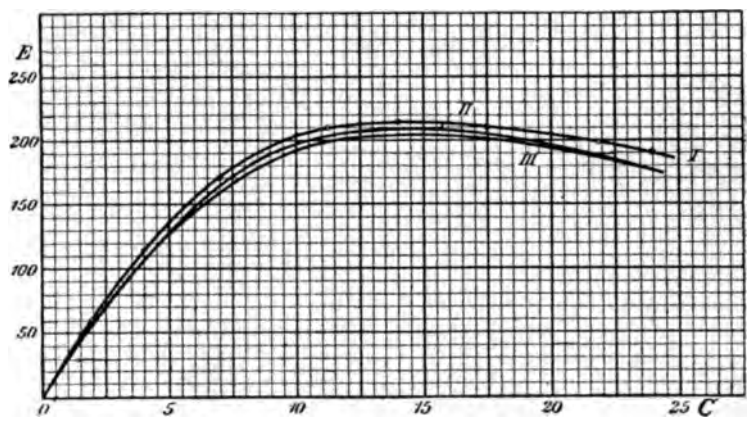



FIG. 132.

In Fig. 132 Curves I.–III. represent the respective characteristics. Considering first Curve I. (which is taken with the brushes in the

neutral position), the difference between this characteristic and that of a shunt machine is very marked. In the case of the latter machine the voltage at no-load is a maximum, whereas that of a series dynamo is practically zero. This is due to the difference in excitation; with a shunt machine the excitation is independent of the load, but with series machines is dependent on the load, *i.e.* the armature current. The external characteristic of a series dynamo would coincide with its magnetization curve if not for the effect of armature reaction and ohmic drop. This is evident in Fig. 133. Curve I. is the external characteristic (Curve I. of Fig. 132), and the straight line II. represents the ohmic voltage drop. By adding the ordinates of I. and II. together,

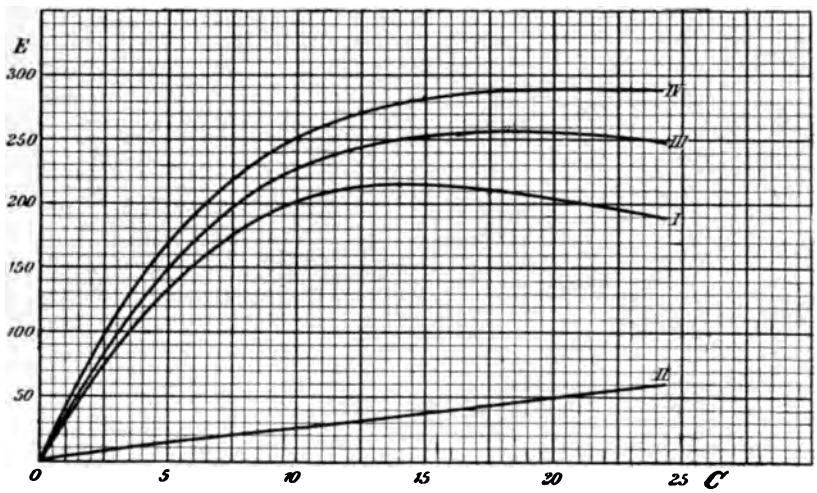



FIG. 133.

Curve III.—the internal characteristic—is obtained. Curve IV. is the magnetization curve of the same machine. The internal characteristic, which is the relation of the E.M.F. and load, lies below Curve IV., and, moreover, the difference of the ordinates is greater with increasing load. Since the difference is due to armature reaction, we see that the latter is not proportional to the load, but increases at a higher rate, with the result that the internal characteristic at higher loads will droop. The external characteristic includes the ohmic voltage drop, and will therefore droop much earlier than the internal characteristic, and this generally occurs soon after the "knee" of the curve is reached.

To determine the relative value of the drop due to armature

reaction and the ohmic drop, we have only to refer to the external and internal characteristics. If both descend simultaneously, armature reaction preponderates; but should the internal characteristic descend later, then the ohmic drop in the armature + field coils preponderates, and the later the droop the greater the action of the ohmic resistance (drop).

Fig. 134 shows the same curves as in Fig. 133, but for another machine.

In Fig. 135 the full lines represent the no-load, external, and internal characteristics of a machine with the brushes in the neutral position, and the dotted lines the same curves, but with the brushes

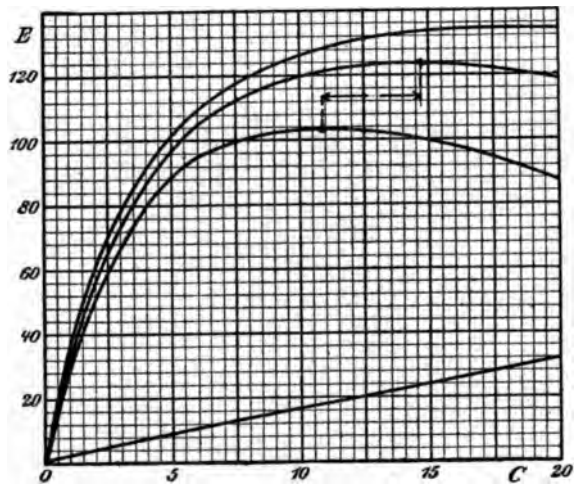



FIG. 134.

shifted from the neutral position (I. and I'., no-load; II. and II'., internal characteristics; III. and III'., external characteristics).

The influence of a large brush displacement is to cause the points of descent of the internal and external characteristics respectively to occur simultaneously. This agrees with what has been said. By shifting the brushes in the direction of rotation, the armature reaction is increased, but the ohmic drop is unaltered.

The speed of the dynamo should be kept constant throughout the experiment, but where this is impossible the results require some correction. Let $n'$ be the constant speed required, $n$ the speed actually measured; then—

$$E_a : E_a = n : n'$$

where $E_a$ and $E_a'$ are the E.M.F.'s induced in the armature corresponding to the speeds $n$ and $n'$ respectively.

Let the corresponding terminal voltages be E and E′, the current C, and the total resistance (armature and field) $r_t$; then—

$$E_a = E + Cr_t$$
$$E_a' = E' + Cr_t$$

thus

$$n : n' = E + Cr_t : E' + Cr_t$$

and

$$E' = \frac{n'}{n}(E + Cr_t) - Cr_t \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

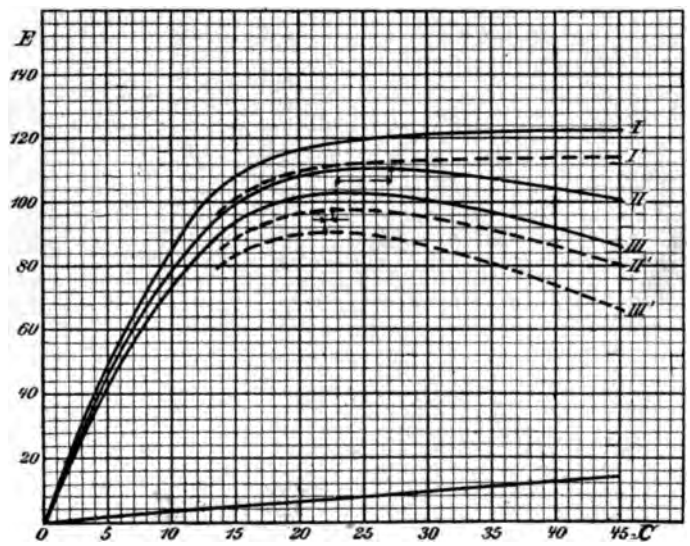



FIG. 135.

By means of formula (20) the terminal voltage may thus be corrected.

In Fig. 136 we have the graphical method for transforming the external characteristic for a speed $n$ to that of a speed $n'$. From the external characteristic (I.), the internal characteristic (II.) can be deduced in the usual way. The ordinates of the latter are reduced or increased in the ratio of the speeds, and from this internal characteristic thus determined the required external characteristic can be readily drawn.

Owing to the variation of resistance of the armature and field

coils, and the consequent variation of the ohmic voltage drop, the external characteristic of a machine when warm will not be the same as in the cold state. Hence in conducting the test the temperature of the machine should always be measured and recorded. From the characteristic determined in the cold state that for the hot state can easily be found by calculation, and *vice versâ*.

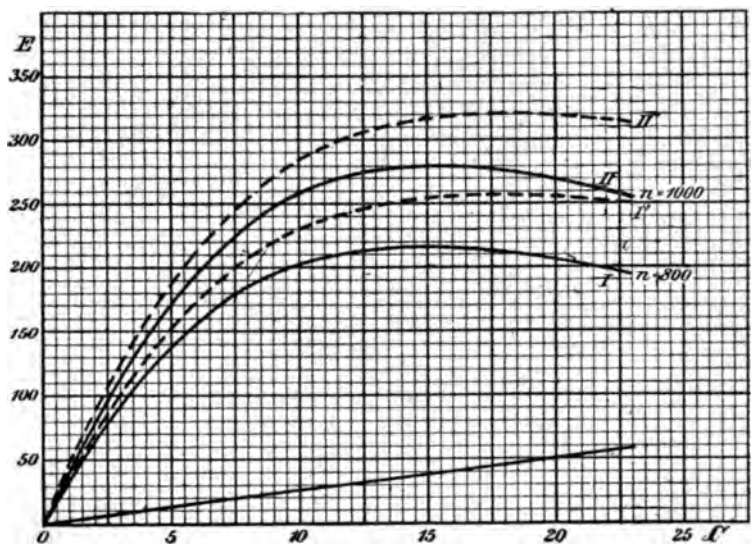



FIG. 136.

## 4. Remarks on the Self-Excitation of Series Dynamos

The conditions for the self-excitation of series dynamos vary but little from those of shunt dynamos. As with the former the whole of the main current flows through the field coils, it is obvious that an excitation is impossible with an open main circuit. By closing the latter, the residual magnetism will produce a small voltage, and hence a current. The value of the residual voltage depends upon the speed, whilst the strength of current produced depends upon the total resistance in circuit, *i.e.* on the resistance of the machine + the resistance of the external circuit. If the total resistance is so large that the terminal voltage required to maintain a certain current in the circuit is greater than the voltage produced by this current,

the machine will not excite. In Fig. 137 Curve I. represents the external characteristic of a series dynamo for $n = 800$. If the external resistance be $70\omega$, a terminal voltage of 175 would be required to produce a current of $2\frac{1}{2}$ amps. But from the characteristic with a main (exciting) current of $2\frac{1}{2}$ amps. the terminal voltage would be but 80. Hence the machine will not excite.

By reducing the external resistance from $70\omega$ to $14{\cdot}8\omega$ (IV.) a voltage of 34 is required to produce the same current as before ($2\frac{1}{2}$ amps.). The terminal voltage for this current being 80, the machine will now excite itself.

We therefore see that for each speed there is certain external resistance, which if exceeded prevents self-excitation. The value of this resistance may be obtained as in the case of a shunt generator. If in Fig. 137 we draw a line representing the external resistance (relation of terminal voltage and main current) we have then three possible cases. The line either intersects, or is tangential to, or meets only at the zero of the characteristic. In the last case the machine will not excite itself at all; in the second case the machine will just start to excite, but the voltage is unsteady; and in the first case the machine will properly excite itself. It will then attain a voltage defined by the point of intersection of the resistance line and the characteristic curve.

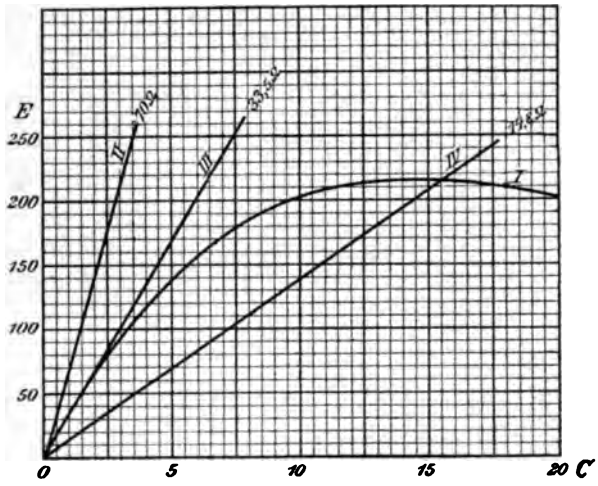



FIG. 137.

The resistance at which the machine will just commence to excite itself, is termed the critical resistance (in Fig. 137, Curve III.), and since the characteristic alters with speed, the critical resistance will correspondingly vary.

Hence in starting a series machine, the procedure differs from that of a shunt machine. In the latter case the main circuit must be open—the machine light. With a series machine the main circuit

must not only be closed, but the external resistance must also be small—the machine with full load.

In starting a compound generator we must proceed as in the case of a shunt machine, *i.e.* the main circuit should be open.

## 5. Series Motors

## Experiment No. XVI

*Characteristic of a Series Motor (Relation between Load and Speed of a Series Motor at Constant Voltage).*

DIAGRAM OF CONNECTIONS.

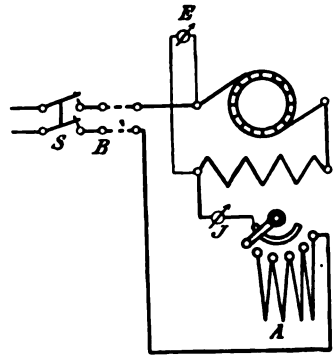



FIG. 138.

*Instruments and Apparatus required.*

J = Ammeter ($1\frac{1}{2}$ times normal current).
E = Voltmeter.
A = Starter.
S = Main switch.
B = Fuse.
One tachometer.
With regard to loading the motor by means of a dynamo, see p. 122.

*Experiment.*—Insert as much resistance in the dynamo circuit as will be required for almost full load of the motor. Then close S and start the motor. If the motor is connected to the full mains pressure, regulate the dynamo load so that the motor consumes a larger current than the normal, say $1\frac{1}{2}$ times as much. Then take readings of the current, the voltage (E), and the speed. Then reduce the dynamo load, namely, the motor load, by increasing the dynamo resistance.

Obtain in this manner motor currents = $1\frac{1}{4}$, normal, $\frac{3}{4}$, $\frac{1}{2}$, etc., and take readings of the corresponding speeds (both the terminal voltage and position of brushes should be kept constant).

If the load be thrown off entirely, the motor might assume a dangerously high speed, *i.e.* "run away." A series motor must therefore never run without load (except in the case of a very small motor, where the no-load watts form a comparatively large part of the total output). If a series motor drives any machine, it should do so by means of a coupling. Belt driving is not very reliable, as, owing to any circumstance—as, for instance, a sudden variation in load—the belt might be thrown off, and the motor thus "run away."

In performing the experiment the speeds enumerated on p. 92 should not be exceeded.

To determine the influence of the brush position on the characteristic curve, another experiment should be made with the brushes shifted backwards.

The results of the experiment should be recorded as follows :—

## Example XVI.

*Characteristic of a Series Motor.*

Machine, No. 457M. Type and maker, 8/5DE, Joseph Adamson & Co., Hyde. Number of poles, 4.

Voltage, 220; current, 17 amps.; output, 4 B.H.P.; revolutions per minute, 500.

Instruments used—Century set.

Table of Results.

| Terminal voltage. | Current. | Speed. | Remarks. |
|---|---|---|---|
| 220 | 18 | 510 | Brushes in neutral position |
| " | 16 | 530 | |
| " | 14 | 560 | |
| " | 12 | 610 | |
| " | 8 | 800 | |
| " | 4 | 1240 | |
| " | 19 | 520 | Brushes moved backwards one and a half bars |
| " | 13 | 600 | |
| " | 8 | 830 | |
| " | 6 | 1000 | |
| " | 5 | 1100 | |
| " | 4 | 1290 | |

The corresponding curves—I. for the neutral position, II. for the second position—are shown in Fig. 139.

From these curves we see that the speed of a series motor decreases with increasing load, and *vice versâ*. From the hyperbolic shape of the curve, we see further that the rate of variation of the speed is smaller the larger the load. For C = 0 the speed would be infinite. Continuing the curve I. (Fig. 139) upwards by estimation, we get Fig. 140, from which we see that for a load of 1·8 amps. the speed of this motor would be equal to about four times the normal, which speed would probably destroy the motor.

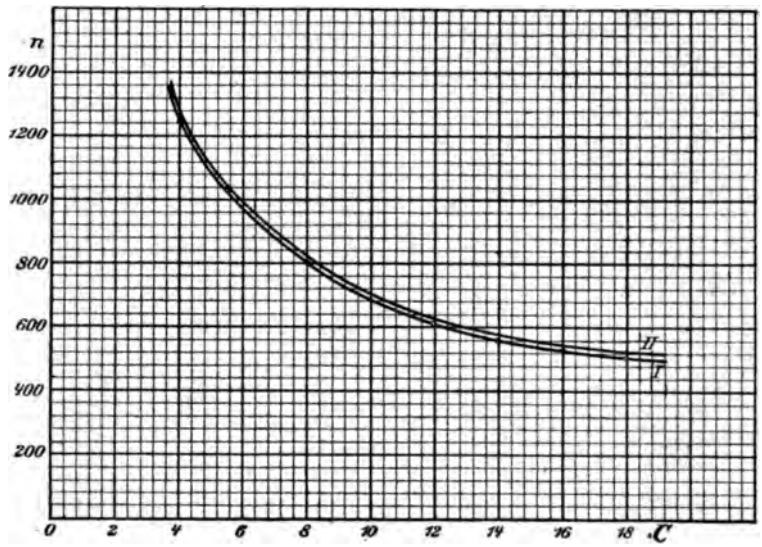



FIG. 139.

The cause of this variation in speed of a series motor with variable load will be clear from the following consideration:—

Let the (constant) terminal voltage be E, the back E.M.F. of the armature $E_a$; then—

$$E_a = E - Cr_t$$

where C stands for the current, and $r_t$ for the total resistance of the motor, *i.e.* $(r_a + r_m)$.

If we plot the back E.M.F. of the armature as a function of the load, we obtain almost a straight line (Fig. 141, Curve I.). Let Curve II. be the magnetization curve (no-load characteristic) of the motor in question for $n = 500$. From these two curves we can draw

a third, corresponding to the internal characteristic of the motor, viz. a curve showing relation between the speed and the load at constant terminal voltage without taking into account armature reaction.

According to formula (16), p. 75, we have—

$$E_a = K \cdot Nn$$

and—

$$n = K_1 \frac{E_a}{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

*i.e.* the speed is directly proportional to the E.M.F. and inversely proportional to the flux. Since the magnetization curve represents the relation between exciting current and flux, and the curve I. the relation between the back E.M.F. and load, the speed curve can be deduced from these curves. Owing to the irregularity of this curve it cannot be expressed mathematically; the conclusions must hence be drawn from the shape of the curve in Fig. 141.

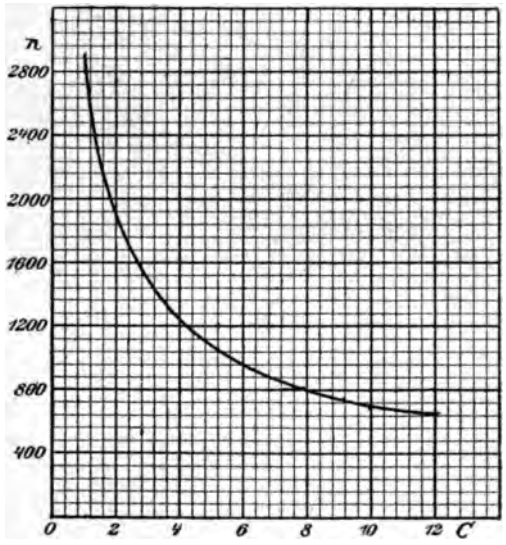



FIG. 140.

For $C = 0, E_a = E$, *i.e.* a maximum, and the flux a minimum, produced by the residual magnetism only. Hence the speed will be very high, and the machine will tend to "run away." If there were no residual magnetism, the speed would theoretically be infinite for $C = 0$, or else the armature will not rotate at all.

By increasing C, the E.M.F. decreases, and the total flux increases, causing a fall in the speed. For the ascending part of the characteristic (*i.e.* for small values of C), the rate of variation of the speed is great, as for this part of the curve the flux grows rapidly. For the flat part of the magnetization curve, the speed curve is also flat, namely, the variation in speed is only small for a large variation

of load. If, finally, the load is increased so that $E = Cr_t$, viz. the voltage drop in the armature and field equals the terminal voltage, then $E_a = 0$, and the motor will stop.

In the above we have neglected armature reaction, and Curve III. shows the theoretical relation between the speed and load. As, however, with a loaded motor armature reaction causes a weakening of the main field, the true speed curve (IV.) will lie above the curve III. The difference between the ordinates of these two curves will be greater the larger the armature reaction, and the further the brushes are shifted from the neutral position. With the brushes in a fixed position, the armature reaction will be greater the larger the

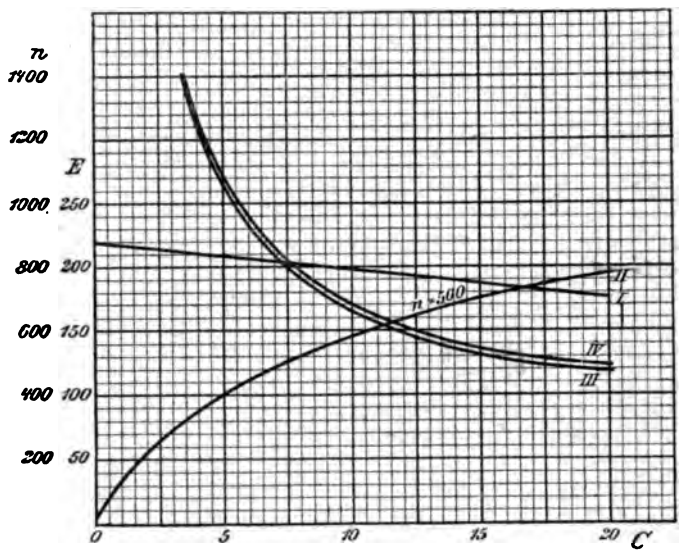



FIG. 141.

load, and with small loads (small inductions) the effect will be greater than with large loads (high inductions).

The special properties of series motors with regard to starting and running become very evident from the characteristic. The torque, developed by a motor, is, we know, directly proportional to its armature current and the strength of the magnetic field. With a series motor the field strength increases with its load; hence it follows that the starting torque is increased from two causes: Firstly, by a starting current larger than the working current (by selecting a proper starting resistance, the starting current may be increased *ad libitum*); and secondly, the large starting current producing a very

strong field. In the case of a shunt motor, the starting torque increases only with the armature current (the field remaining practically constant at all loads). The torque of a shunt motor can only be increased so far as the overheating of the armature will allow. With a series motor, however, the increase of the armature current need not be as great as the increase in torque. For instance, with a normal series motor we require but one and a half times the normal current, if the motor is to develop twice the normal torque. From this point of view, the series motor is certainly superior to the shunt motor, and will therefore always be employed in cases where a great starting torque is required, and in which sudden and heavy overloads are likely to occur.

With regard to the speed regulation of the two kinds of motors under discussion, we have learnt that in the case of the shunt motor it is self-regulating within certain limits (*i.e.* runs with nearly constant speed). The small drop in speed, caused by the ohmic voltage drop, may easily be compensated by a small shunt regulator. On the other hand, we have seen that the speed of a series motor is not constant, but varies within very wide limits.

With a shunt motor a downward regulation of speed can be effected by inserting resistance in the armature circuit; the loss in such a resistance is, however, very considerable, and the efficiency decreases in the same proportion as the speed decreases. The torque is obviously not affected by this regulation, but the variations in speed due to variations in load are considerably larger.

An upward regulation of speed may be effected by weakening the shunt current, *i.e.* by weakening the field. With this regulation the torque decreases in the same degree as the field is weakened. A motor will be of less utility the wider the limits of regulation. For should the motor develop a constant torque at all speeds, its armature will have to consume larger currents with higher speeds, and smaller currents with lower speeds. But the armature must be designed for the maximum current, and will consequently have to be made larger than would be the case if the motor were not constructed for variable speed.

The speed of a series motor can obviously also be reduced by inserting resistance, and we obtain in this manner an approximately constant speed for a varying load. In Fig. 142 is shown the influence of the resistance on the speed of the motor. A represents the no-load characteristic of the motor (running as a dynamo), I.–V. represent the relation between E.M.F. and load, and 1–5 the relation between speed and load with the respective resistances in the circuit. In our example, the speed is to be kept constant at about 1500 revolutions per minute. From curve 1, we see that, with normal load and without any series resistance, the speed will be about 1400. The

armature + field resistance of this machine equals $\frac{1}{3}\omega$ approximately. By reducing the load, the speed of the motor increases; with $c = 25$, $n =$ about 1550. If a resistance of $0{\cdot}7\omega$ (the total resistance then being $1\omega$) be inserted, the speed will drop to 1500. This brings us to curve 2. By reducing the load from 25 to 22 amps. the speed will rise to 1600, and an added resistance will reduce the latter to 1500. The load can further be reduced until with a series resistance of $1{\cdot}7\omega$ (*i.e.* a total resistance of $2\omega$) and a load of 13·5 amps., the speed rises again to 1600. We gather from this that with a resistance of about $1{\cdot}7\omega$, the speed of the motor can be kept nearly constant for all loads between 13·5 and 30 amps.—and conclude also that the motor could be prevented from "running away" at no-load by means of a very large resistance.

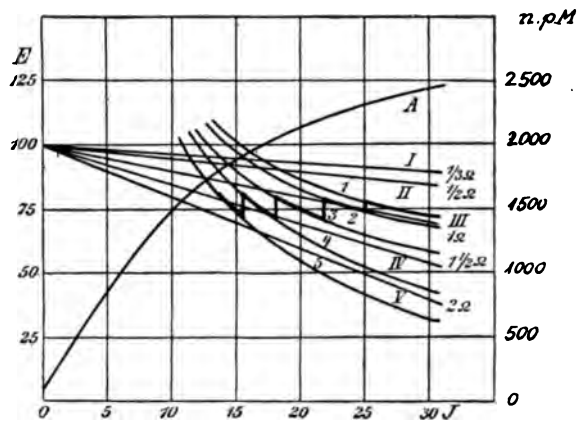



FIG. 142.

An upward regulation of speed of a series motor can also be effected by weakening the field. For this purpose either a resistance may be connected in parallel with the field coils, or the field coils may be solely connected in parallel. Let $m$ be the number of turns per coil, and $n$ the number of field coils—then with a load of C amps., and all coils connected in series, the total ampere-turns will be $n \cdot m \cdot C$. If the field coils are in parallel, the ampere-turns will be $n \cdot m\frac{C}{n} = mC$. This method of speed regulation is frequently employed with tram motors.

From the above comparison of the starting and working properties of series and shunt motors, we can summarize their field of application. In all cases in which a constant speed is essential for

different loads, and in which the attendance is restricted to a minimum, a shunt motor should be employed. But in cases where a great starting torque is required, and where a large torque has to be developed at small speeds and a small torque at high speeds, series motors should be used. Thus, for traction purposes, lifts, cranes, etc., the series motor is especially suitable. As in nearly all these cases enumerated the motor is directly coupled to a gearing, its tendency to assume an excessive speed at no-load is no disadvantage.

## 6. Compound Machines

We have seen from the characteristics of shunt and series generators that the voltage of the former falls with increasing load, whilst that of the latter rises. These properties therefore guide us in the construction of compound generators. These have combined series and shunt field windings. As the voltage drop of a shunt machine with full load is relatively small, only a small number of compounding (series) turns is required.

The connections of a compound machine can be effected in two different ways, as shown in Figs. 143 and 144.

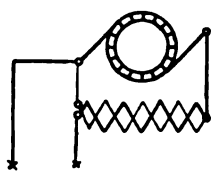


FIG. 143.

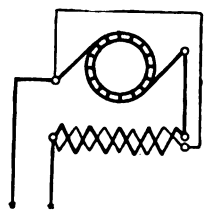


FIG. 144.

The shunt winding may be connected across either the armature terminals (Fig. 143) or the machine terminals (Fig. 144).

There is no essential difference between these connections. With no-load the terminal voltage is practically equal to the armature voltage. The shunt current will therefore be the same in either case. With load there will be a voltage drop in the series windings, so that the terminal voltage will be somewhat smaller than the armature voltage, and thus the current flowing through the shunt winding of Fig. 143 will be a little larger than in the case of Fig. 144. The former connection is called "short shunt," the latter "long shunt." The difference then between these connections is that with load the voltage of the machine with the "short shunt" will be slightly greater than that of the machine with the "long shunt" connection.

## Experiment No. XVII

*Characteristic of a Compound Dynamo (Relation between Load and Terminal Voltage of a Compound Dynamo at Constant Speed).*

DIAGRAM OF CONNECTIONS.

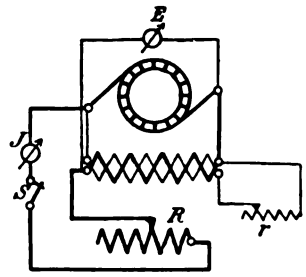



FIG. 145.

*Instruments and Apparatus required.*

E = Voltmeter (normal voltage).
J = Ammeter (0–$\frac{5}{4}$ of the normal current).
R = Main resistance.
S = Main switch.
One tachometer.

*Experiment.*—Adjust the brushes in the neutral position, and bring the dynamo up to normal speed. With the switch S open, adjust the voltage by means of the shunt regulator R to its normal voltage. Record the voltage and speed, and afterwards close S, noting that all the resistance R is in circuit. Increase the load gradually by cutting out part of the resistance R, and read the current (J) and the corresponding voltages (E).

During the experiment *r* should not be altered nor the brushes shifted, and the speed should remain constant.

Record the results as below.

### EXAMPLE XVII.

Machine No. 1542. Type and maker, Mather and Platt. Number of poles, 2.

Voltage, 110; current, 55 amps.; output, 6 K.W.; revolutions per minute, 1000.

Instruments used—Century set.

TABLE OF RESULTS.

| Current. | Voltage. | Speed. |
|---|---|---|
| 0 | 112·6 | 990 |
| 12 | 111·4 | " |
| 16 | 111·2 | " |
| 22 | 110·9 | " |
| 35 | 110·2 | " |
| 43 | 109·8 | " |
| 50 | 109·2 | " |
| 60 | 108·8 | " |

The results of this experiment are plotted in Fig. 146. It is evident from this curve that the compounding of the above machine is very good, namely, the maximum variation of voltage is small. It will generally be found that the voltage variation

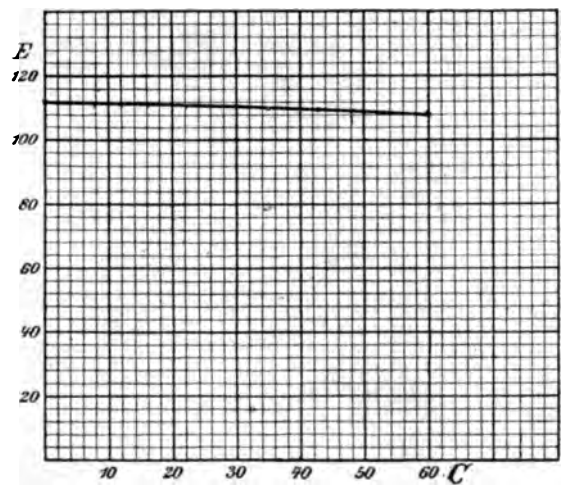



FIG 146.

of compound machines is larger than that shown in Fig. 146, unless the number of series winding has been very carefully determined, as was the case with the above machine.

Examples of characteristics, as are frequently met with in practice, are shown in Figs. 147 and 148.

The machine for Fig. 147 is not sufficiently compounded. The reason of this is not necessarily due to too small a number of series turns, but may also be due to a wrong position of the brushes. With machines in which the compounding is insufficient, an improvement may sometimes be effected by shifting the brushes or varying the excitation and the speed, for the compounding of a machine does not only depend upon the number of series turns, but also upon the position of the brushes, in connection with the initial excitation. To vary the excitation a shunt regulator should always be provided (see Fig. 145).

The characteristic of a machine, which is properly compounded, is shown in Fig. 148. The voltage of this machine rises above

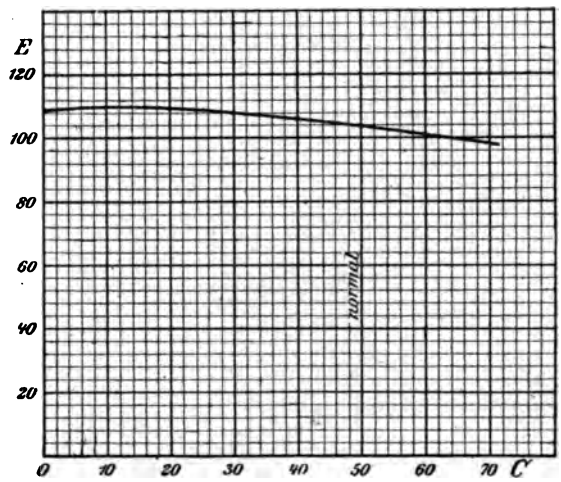



FIG. 147.

the normal, and then falls below it. It may be mentioned here that, even theoretically, it is impossible to construct a perfect compound machine, *i.e.* a machine with a horizontal characteristic. This is obvious from the following consideration: The voltage drop of a shunt machine is caused by the ohmic resistance of the armature and by the demagnetizing and cross-magnetizing armature ampere-turns. The effect of the latter increases more rapidly than the armature current, with higher loads even considerably more. Hence, to compensate the effect of armature reaction, the additional (series) ampere-turns should increase more rapidly than the load. This is of course impossible, as the series ampere-turns can only be proportional to the load. Neglecting the effect of ohmic resistance, the voltage of a compound dynamo will therefore be bound to fall with the high loads, and since the

compensation of the ohmic voltage drop needs a certain number of ampere-turns, the ampere-turns required for compensating the total drop will require to be larger, the smaller the permeability of the iron path, *i.e.* the higher the saturation of the iron. (The saturation of the iron parts of a compound machine increases with increasing load.) If the additional (series) ampere-turns are selected so that they will compensate the drop due to ohmic resistance, at say half the normal load, then, at all loads below half-normal, they will cause the voltage to be higher than required, and for higher loads they will not suffice, and consequently the voltage will fall below the normal.

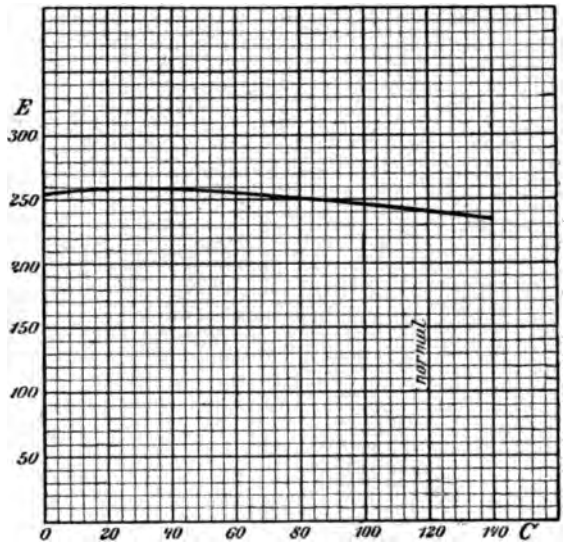



FIG. 148.

By selecting a certain number of series turns we can make the voltage of a machine rise at say $\frac{1}{2}$–$\frac{2}{3}$ of the normal load, then to assume the normal voltage, and finally fall below the normal voltage at still higher loads (see Fig. 148). The machine can also be wound so that its voltage rise first reaches a maximum at half-load, and then falls to normal voltage again at full load. A characteristic of such a machine is shown in Fig. 149. Obviously the percentage variation of voltage will be greater, with a machine as in Fig. 149, than with a machine as in Fig. 148. The former will be suitable for pure power transmission. For lighting purposes, where the variation of voltage should be as small as possible, a characteristic as in Fig. 148 is more preferable.

By suitably increasing the number of series turns of a compound dynamo, its voltage will—within certain limits—rise with increas-

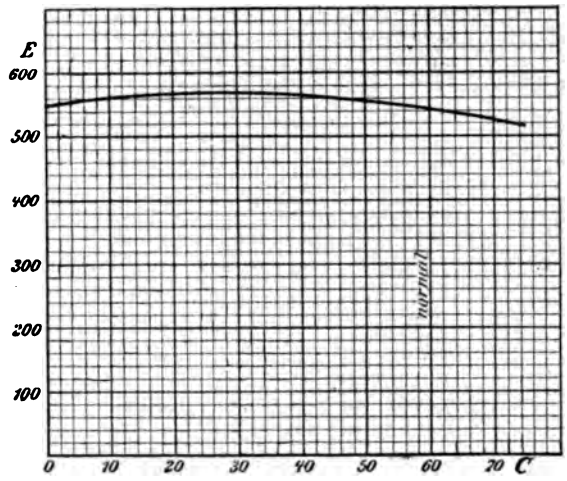



FIG. 149.

ing load. Such a machine is said to be "over-compounded." The characteristic of an over-compounded dynamo is shown in Fig. 150.

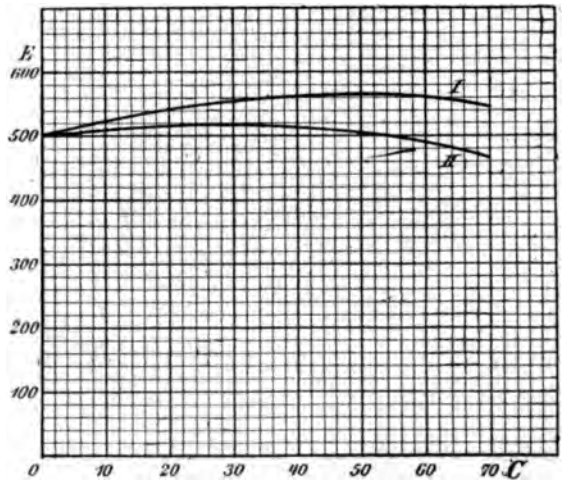



FIG. 150.

The function of an over-compounded dynamo is to keep the

voltage at a distant feeding-point constant. Suppose the machine has to feed a network, and the total resistance of the feeder equals $1{\cdot}2\omega$, then, with a load of 10 amps., the voltage at the distant end of the feeder will be 510, with 20 amps. 516, with 30 amps. 514, etc. In Fig. 150 the voltage at the distant end of the feeder is plotted as a function of the load (Curve II.). From this curve we see that, notwithstanding the comparatively big voltage drop in the feeder, the voltage at the feeding-point is kept fairly constant.

The automatic and momentary voltage regulation of compound dynamos makes them suitable for many purposes—for instance, small lighting plants—which should work without a constant attendance. As a matter of fact, the compound machine has for a long time been exclusively employed in such plants. On the other hand, working in parallel with accumulators is more difficult with compound than with shunt machines. For large plants, especially those employing accumulators, shunt dynamos are mostly used.

## Experiment No. XVIII

*Determination of Series Turns for a Compound Dynamo.*

DIAGRAM OF CONNECTIONS.

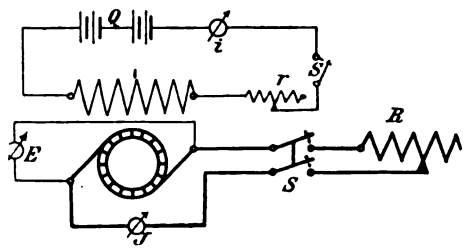



FIG. 151.

*Instruments and Apparatus required.*

E = Voltmeter (normal voltage).
J = Ammeter (20 per cent. overload).
R = Main resistance.
S = Double pole switch.
$i$ = Shunt ammeter.
$r$ = Shunt resistance.
$s$ = Field switch.
Q = Source of E.M.F. for separate excitation. Pressure, about 30–50 per cent. above dynamo voltage.
One tachometer.

*Experiment.*—The series turns required for compounding a generator can be obtained by calculation. Such a calculation is, however, rather complicated, and, as it must be founded on a number of assumptions, it is not very reliable. In practice the number of series turns is generally determined by experiment, the shunt turns being wound first and sufficient space left for the series turns, the approximate number of which is estimated as in the following:—

First bring the machine to its normal speed (which must be kept constant during the experiment), adjust the brushes in the neutral position, and open the main switch S. Then close the field switch, and regulate the voltage of the machine (E) to the normal by means of the shunt regulator. Read the shunt current. Then close the main circuit by means of the main switch S, with all the resistance R in circuit. The voltage of the machine will fall slightly owing to the load, and by increasing the shunt current—cutting out part of the shunt resistance—the terminal voltage is increased again to its former value (normal). Increase the load gradually, regulating the voltage always to the normal, and take readings of the main and shunt currents. The speed and, if possible, the position of the brushes must be kept constant.

## Example XVIII.

*Determination of the Number of Series Turns for a Compound Generator.*

Machine, No. 13112. Type and maker, Crompton & Co.

Voltage, 250; current, 10 amps.; output, 2½ K.W.; revolutions per minute, 900.

Instruments used—Weston Volt-ammeter.

Table of Results.

| Main current. | Voltage. | Speed. | Shunt current. |
|---|---|---|---|
| 0 | 250 | 900 | 0·425 |
| 1·6 | " | " | 0·44 |
| 3·0 | " | " | 0·46 |
| 4·8 | " | " | 0·485 |
| 7·2 | " | " | 0·525 |
| 8·8 | " | " | 0·565 |
| 9·9 | " | " | 0·6 |

Remarks.—Number of shunt turns, 4000 per coil.

To determine the number of series turns that of the shunt must be known. We can then find the total number of ampere-turns required to keep the voltage constant by simply multiplying the shunt currents (see above table) by the number of shunt turns. In Fig. 152 the ampere-turns are plotted as a function of the load. Obviously the ampere-turns required for no-load must be supplied by the shunt winding only. In our example these ampere-turns amount to about 1700. The shunt winding will supply these ampere-turns at all loads. From the curve we see that the number of ampere-turns required increases with the load. The difference between the total ampere-turns required at any particular load and the constant shunt ampere-turns must be produced by the series winding. We call

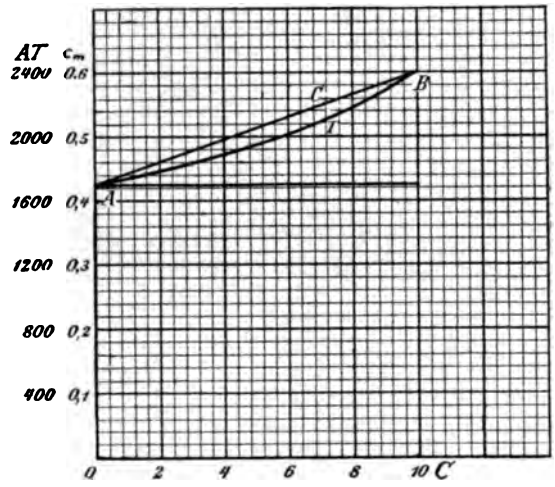



FIG. 152.

these "additional" ampere-turns. To find the number of series ampere-turns we divide the number of additional ampere-turns for any load (current) by the series or main current. If the plotted curve in Fig. 152 were a straight line, the number of series turns required would be the same for all loads. As, however, we know this not to be the case, we must proceed in one of the following ways: A straight line can either be drawn through the end points of the curve (A, B), and the number of series turns thus determined (in our example 70) —the machine will then be supplying normal voltage at no-load and full-load, and for any intermediate load the voltage will rise above normal (see also Fig. 149)—or the straight line may be drawn so that it intersects the curve I in C, say at about two-thirds of the

normal load. The voltage of the dynamo will then be normal at no-load, and with increasing load the voltage will rise; be normal again at about two-thirds of the normal load; and finally fall below normal for any load above two-thirds normal (see also Fig. 148).

In a similar manner the number of series turns can be determined for an over-compounded dynamo. In performing the experiment, the voltage must then be gradually raised as far as is required for over-compounding. The additional ampere-turns will naturally be greater for an over-compounded machine than for a compound.

Strictly speaking, in performing the experiment, the voltage drop taking place in the series turns should be considered. This, however, is generally so small that it can be neglected.

It may finally be mentioned that a compound dynamo is generally provided with a shunt regulator. This regulator serves the double purpose of adjusting the initial voltage of the machine and to compensate the variation in resistance of the shunt winding due to overheating.

# CHAPTER VIII

# MAGNETIC MEASUREMENTS

## 1. Determination of the Magnetic Leakage or Stray Coefficient

THE majority of the lines of force produced by the magnetizing ampere-turns passes through the air gaps and the armature core. The remainder—the stray lines—cannot be utilized. The ratio between the number of lines of force produced and the useful lines in the armature is called the magnetic leakage or stray coefficient, and is evidently greater than 1.

The coefficient can be found experimentally by winding a number of turns round the parts of the magnetic circuit for which the coefficient is required. The number of turns should be the same for both coils. If the field be weakened by a certain amount, the number of lines of force extracted from each of these coils can be found by means of a ballistic galvanometer, and from the results the number of lines passing through the field magnets and armature respectively can thence be deduced. The ratio of these numbers represents the stray coefficient.

With this measurement, however, we must note that the stray coefficient depends on the degree of saturation of the iron circuit. Hence the different values of the coefficient must be measured for various inductions, taking precaution that the variation of the field strength is small; otherwise the stray coefficient measured would not correspond to the particular saturation, but to an average value between the limits of the saturation.

The ballistic method, though one of the most accurate, has the disadvantage of being tedious and troublesome. For practical measurements, the differential method as devised by Goldschmidt should be employed.

The principle of this method is as follows: Two coils $s_1$ and $s_2$ opposing one another (see Fig. 153) are connected in series with a

millivoltmeter. The number of turns of $s_1$ and $s_2$ are varied until the voltmeter shows no deflection if the strength of field is suddenly changed. We have then the relation—

$$\frac{N_2}{N_1} = \frac{s_2}{s_1}$$

where $N_1$ is the number of lines of force flowing through $s_1$, and $N_2$ that flowing through $s_2$.

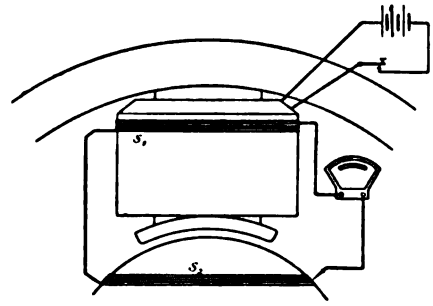


FIG. 153.

This equation is only correct if the time required for the variation of lines of force is small compared with the natural period of swing of the moving part of the instrument; which condition is nearly always fulfilled in practical cases.

The larger the number of turns on the two coils, the more accurate will the experiment be. With a small number of windings it will generally be impossible to make the deflection of the voltmeter zero. In such a case, positive and negative deflections should be obtained by varying the ratio $\frac{s_2}{s_1}$; the correct stray coefficient can then be found by interpolation.

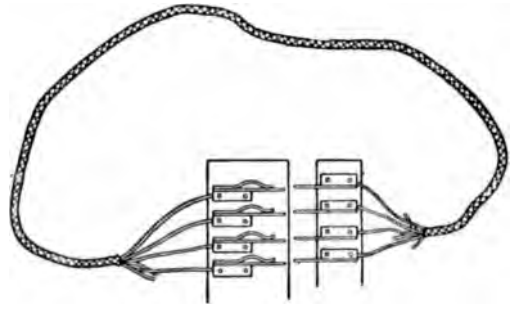


FIG. 154.

To obtain a quick variation of the number of turns, an arrangement as shown in Fig. 154 can be used. The open turns are wound on the pole piece, and closed simultaneously by pushing the plugs into the contacts. The number of turns can be varied by connecting to different contacts.

## 2. Field Distribution and Potential Curves

The influence of the armature reaction on the magnetic field has been discussed in the general remarks of Chapter VII. It was

stated that the magnetic field which at no-load is practically homogeneous, becomes distorted by armature reaction, and moreover, this distortion of the field depends upon both the strength of the armature current (load) and the position of the brushes.

In giving the characteristics of a machine the knowledge of the distribution of the lines of force underneath the pole pieces is of great importance. The field curves of a machine should hence be determined, together with the characteristic curves. Before proceeding to describe the experiments for the determination of the field distribution, a few remarks may be made about the armature field and its reaction on the magnet field.

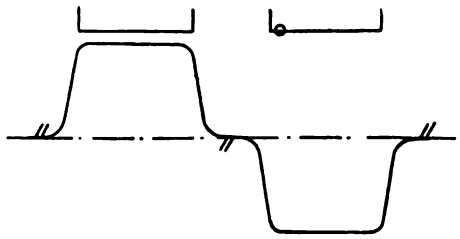


Fig. 155.

If by any of the experiments described subsequently, the field distribution round the armature of a fully excited but unloaded machine is determined, and the values of the field strength thus found be plotted as a function of the angle of position, under which they have been measured, a curve similar to that shown in Fig. 155 will be obtained. This curve shows that the field is a minimum (or zero) in the neutral zone, increases as we approach the pole piece, and is a maximum and nearly constant underneath the pole piece. In Fig. 155 the positions of the pole piece and the brushes are also indicated.

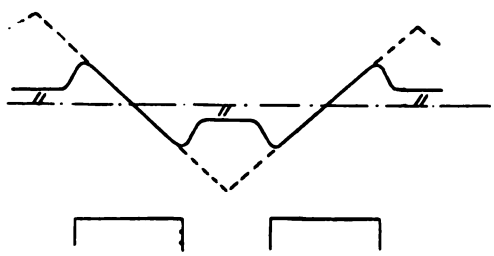


Fig. 156.

With the passage of current through the armature, the armature ampere-turns produce a field, the strength of which depends on the strength of the armature current, the number of conductors on the armature, and the size of the air gap. The two latter are constant for any particular machine, so that—neglecting the reluctance of the iron circuit—the armature field depends only on the strength of the current. If the distribution of the armature field be determined—which may, for instance, be performed by sending a current through the armature, and driving the machine without exciting it—we get a curve similar to that shown in Fig. 156 (full line). In this figure,

too, the positions of the pole shoes and brushes are indicated. The peculiar shape of this curve will be clear from a study of the Figs. 157 and 158. Fig. 157 represents a machine with a closed pole shoe-ring.

Such a machine is of course not made, but it will serve the purpose of explaining the character of the curve in Fig. 156. If we cut the pole shoe-ring and the armature of such a machine and develop them in a plane, we obtain Fig. 158. The direction of the armature currents is indicated both in Figs. 157 and 158. Since the air gap is the same at all points, and the armature ampere-turns per cm. are the same all over the circumference, the field produced by the armature will have the triangular shape as indicated in Fig. 158. As mentioned above the reluctance offered to the lines of force by the armature and the pole piece has been neglected. By moving the brushes from position 1,2,1 to position 1′,2′,1′ the shape of the curve is not altered, but its relative position is changed (see dotted curve in Fig. 158).

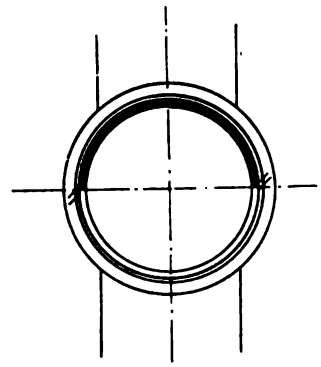


Fig. 157.

As in nearly all machines the pole shoes are separate from each other, the curve representing the armature field is correspondingly altered. In the neutral position where the distance between the

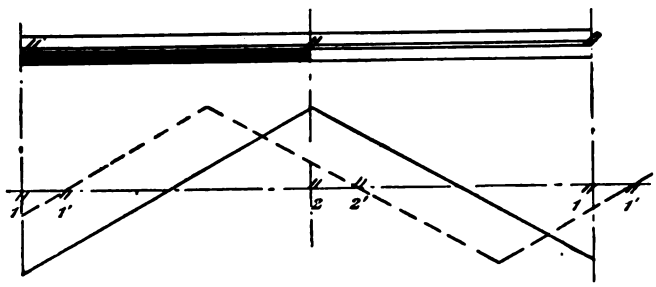



Fig. 158.

armature surface and the pole shoe, and thus the magnetic reluctance, are the greatest, the armature field is practically zero. The nearer we approach the pole shoe, the closer will the field curve coincide with that shown in Fig. 158, and this explains the particular shape of the curve shown in Fig. 156.

When the machine runs with full excitation, the fields produced by the magnets and the armature will combine to produce a resultant field. The strength and the distribution of this resultant field depend therefore upon the strength and distribution of the individual fields and upon the relative position with respect to each other. The magnet field has a fixed position, and the armature field an altered position, by shifting the brushes.

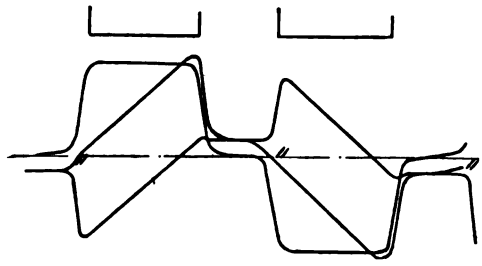


FIG. 159.

If therefore two of these field curves are found by experiment, the third—the resultant—can be determined graphically. It must, however, be mentioned that this combination of two fields does not always give correct results; the reason being that the ampere-turns producing these fields, and not the fields, should be combined. A further source of inaccuracy is the residual magnetism, so that the field curve for full load determined experimentally is generally below the curve obtained by combining the field and the armature curves.

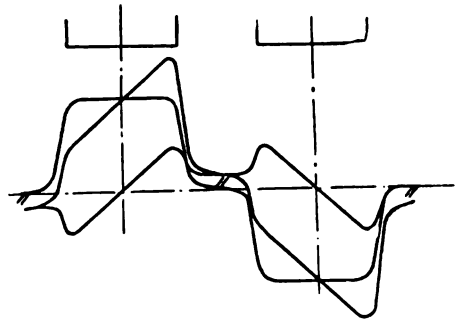


FIG. 160.

In Figs. 159 and 160 is shown the influence of moving the brushes on the resultant field curve. These curves are obtained graphically from the curves in Figs. 155 and 156.

## 3. Experimental Determination of Field Distribution Curves

The various modes of determining field distribution curves are—

(*a*) By means of a bismuth spiral.
(*b*) Measuring the voltage between adjacent commutator bars.
(*c*) By means of a test coil.

The first method (*a*) has the advantage of being capable of application to a stationary armature; the method (*c*) is especially suitable for measuring the strength of field at certain points. The method of measuring the voltage between adjacent commutator bars is the simplest one, and most frequently used in practice.

### (*a*) Determination of Field Curves by a Bismuth Spiral.

Bismuth has the property of increased ohmic resistance when brought into a magnetic field, the resistance increasing with the strength of field. Thus for any induction we have a corresponding ohmic resistance.

Bismuth spirals are employed to measure directly the induction in the air gaps of machines. They consist of insulated bismuth wire, which is doubly wound in a spiral, and the ends of the wires lead to terminals on an insulating handle. The spiral is flat and very thin, being protected against mechanical injury by two mica plates. It can be easily inserted in very small air gaps.

The spiral is calibrated by placing it between the poles of a very powerful magnet. The induction in the air gap is varied, and measured by a ballistic galvanometer. The ohmic resistance of the spiral is simultaneously measured, and thus a curve is obtained representing the induction as a function of the ohmic resistance. It must, however, be pointed out that the ohmic resistance of the bismuth wire varies also with the temperature; hence the calibration curve is correct only for the temperature at which it has been determined. Calibration curves must therefore be obtained for several temperatures, or the following formula may be used for corrections:—

$$B = B_1 \left\{ 1 + \frac{0{\cdot}35(t - t_1)}{100} \right\} \quad . \quad . \quad . \quad . \quad . \quad (22)$$

where $B_1$ stands for the induction deduced from the calibration curve.
$t_1$ „ „ temperature at which the calibration curve has been determined.
$B$ „ „ true value of the induction at temperature $t$.

When determining the field curve of an unloaded machine it must be fully excited. When determining the armature field the magnets must not be excited, but the full current must be sent through the stationary armature.

If, finally, the resultant field curve is to be determined, the excitation, armature current, and the brushes must be adjusted corresponding to the normal working of the machine. The field

curve thus determined does not, however, show the effect of the short-circuited coils on the resultant field.

Besides the advantage mentioned above, the method described has the further advantage that the results obtained are in absolute measure (*i.e.* in lines per sq. cm.), whilst, as we shall see further on, the other methods give only relative values.

### (*b*) Determination of Field Curves by Measurement of Voltage between Adjacent Commutator Bars.

When a coil rotates with uniform speed in a magnetic field, the E.M.F. induced in it will at any moment be directly proportional to the strength of the field in which the coil moves. Thus the voltage measured at the ends of a coil, or at the commutator bars to which this coil is connected, will give a measure of the field strength influencing the coil at that moment.

Fig. 161 shows an arrangement for measuring the strength of field. If two brushes, the distance between which is equal to the width of a commutator bar, slide on the commutator of an ordinary ring armature, then the voltage measured by these brushes will be proportional to the mean strength of the field in that space in which the respective coil rotates. It should be noted, that in this method the mean strength of the field between two points is measured, and not the field strength at one point. The distance of the points, between which the mean field strength is measured, depends upon the type of winding and on the number of commutator bars.

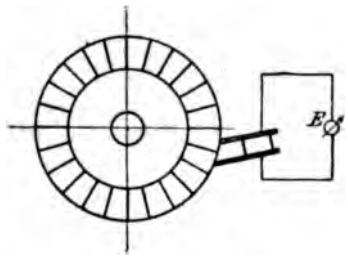



Fig. 161.

If the armature carries no current, the voltage measured by the two auxiliary brushes equals the E.M.F. induced in the coil. If, however, the machine is loaded, the voltage measured by the auxiliary brushes will be smaller or larger than the E.M.F. induced, according as the current and the E.M.F. have the same direction or not

With regard to the commutator bars between which the voltage should be measured, the following points should be noted:—

With lap windings the voltage must be measured between two consecutive bars; also with wave windings, in which the ratio

$$\frac{\text{number of poles}}{\text{number of armature sections in parallel}}$$

is a whole number.

With wave windings in which the above ratio is a fraction, the voltage must be measured between two bars distant by $a$ ($2a =$ number of armature sections in parallel).

In a six polar machine having four armature sections in parallel, for instance, the voltage must be measured between any two bars distant by two, *i.e.* between bar 1 and 3, 2 and 4, etc.

With windings having a normal pitch the absolute strength of field may be found from the E.M.F. induced, the length of the coil, its speed, and the number of conductors per coil.

(*c*) Determination of Field Curves by Means of a Test Coil.

If the strength of field is required at certain points, it will be best accomplished by means of a test coil. This coil must be arranged so that its pitch is equal to the width of the pole shoe; its ends must be connected with a contact disc and a ballistic galvanometer. If necessary, a suitably high resistance should be connected in parallel with the latter. By means of the contact disc and the brushes both the moment and the duration of the experiment may be varied at will.

With windings in which the pitch is normal (not small) one armature coil may be used as the test coil. The commutator bars which lead to the ends of this coil must then be connected to two separate slip rings.

## 4. Potential Curves

If on a rotating armature the voltage is measured between one of the main brushes and a movable auxiliary brush, and this voltage

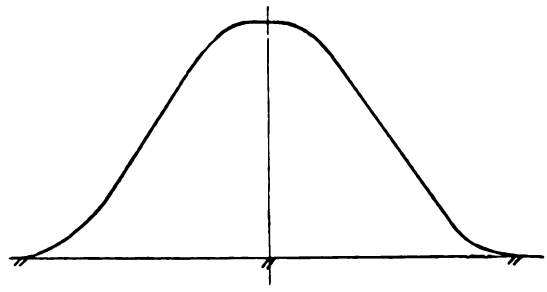


Fig. 162.

plotted as a function of the commutator circumference, a curve is obtained similar to that shown in Fig. 162.

Such a curve is called the potential curve. It indicates how much the individual coils contribute to the total voltage.

With simple lap and spiral windings the potential curve may be obtained from the field curve by plotting the sum of the voltages between the consecutive bars against the position of the bar, since, with the windings mentioned above, the potential curve is equal to the sum of the field curves.

# CHAPTER IX

# EFFICIENCY

## Introduction

As in the case of other transformations of energy, in the conversion of electrical into mechanical, or *vice versâ*, losses arise which, with dynamos and motors, are of an electrical (magnetic) and mechanical nature. The value of these losses (*i.e.* the determination of efficiency) is, from the reasons given in Chapter III., of great importance. Though from a commercial point of view the knowledge of the total efficiency is quite sufficient, it is very important for the designer of an electric machine to know how the total losses arising in a machine are comprised. We shall therefore not only deal with the various methods for the determination of efficiency of dynamos and motors, but also the methods of finding and separating the individual losses.

The efficiency ($\eta$) of a machine is equal to the ratio of the power delivered ($P_d$) and the power consumed ($P_c$); thus:

$$\eta = \frac{P_d}{P_c}$$

Consider the transformation of energy in the case of a generator. A part of the mechanical energy supplied to the generator is lost or rather transformed into heat by the mechanical and magnetic frictions. The remainder of this energy is transformed into electrical energy. But not all of the latter can be employed usefully; part of it is required to excite the machine, and another part is lost in the armature winding (ohmic loss).

With a motor, of the electrical energy supplied a part is lost in exciting the machine and overcoming the ohmic resistance of its armature. The remainder is transformed into mechanical energy, from which, however, a part is lost in overcoming the mechanical and magnetic resistances.

Hence three different kinds of efficiencies may be considered, viz. the mechanical, electrical, and combined or total efficiencies. The mechanical efficiency is of no special interest, and whilst in some cases the electrical efficiency is important, in all cases the combined, total, or commercial efficiency is of the greatest importance.

## 1. The Electrical Efficiency

As stated above, the electrical efficiency ($\eta_e$) is the ratio between the *electrical* energy delivered to that consumed.

Let $P_c$ be the electrical energy consumed.
$P_d$ „ „ „ delivered.
$r_a$ „ armature resistance (total, including the contact and brush resistance).
$r_m$ „ shunt resistance.
$C_a$ „ armature current.
$c_m$ „ shunt current.
$r_s$ „ resistance of the series winding.

Then—

$$\eta_e = \frac{P_d}{P_d + C_a^2 r_a + c_m^2 r_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

for shunt machines,

$$\eta_e = \frac{P_d}{P_d + C_a^2(r_a + r_s)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

for series machines, and

$$\eta_e = \frac{P_d}{P_d + C_a^2(r_a + r_s) + c_m^2 r_m} \quad . \quad . \quad . \quad . \quad (25)$$

for compound machines.

Hence the electrical efficiency of a machine becomes determinable when the resistances of the armature and field coils are known. The measurement of these resistances is described in Chapter II.

In the following are three examples for determining respectively the electrical efficiency of

(*a*) A shunt machine.
(*b*) A series „
(*c*) A compound „

(*a*) SHUNT MACHINE.

The machine is self-excited, and without a shunt regulator.
Voltage, 110; current, 30 amps.; output, 3300 watts.
Total armature resistance: $0{\cdot}25\omega$ } hot.
Field resistance: $85\omega$ }

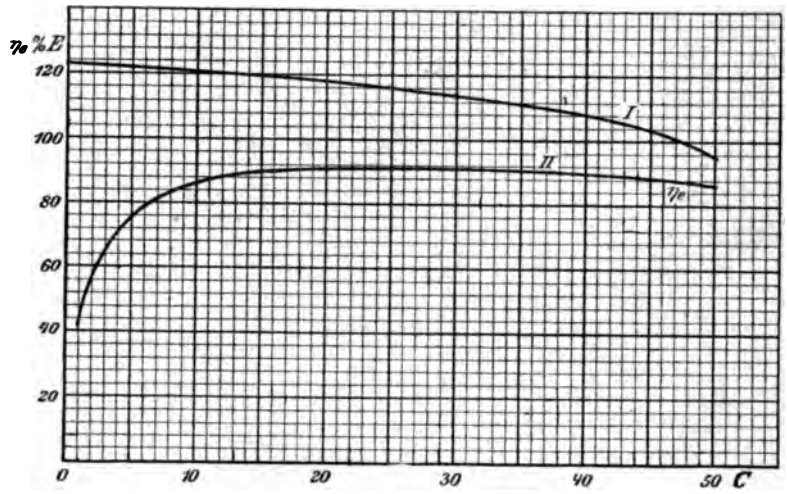



FIG. 163.

Curve I. in Fig. 163 represents the external characteristic of the machine. In calculating the electrical efficiency we must consider the variable exciting current owing to varying terminal voltage—the field resistance being constant.

According to formula (23)

$$\eta_e = \frac{P_d}{P_d + C_a^2 r_a + c_m^2 r_m};$$

For $c_m^2 r_m$ we can put $\frac{E^2}{r_m}$. For any load C the corresponding value of E may be found from Curve I. Thus for—

| | |
|---|---|
| C = 2 | $\eta_e = 58\%$ |
| C = 5 | $\eta_e = 77\%$ |
| C = 10 | $\eta_e = 86\%$ |
| C = 20 | $\eta_e = 90\%$ |
| C = 30 | $\eta_e = 90\%$ |
| C = 40 | $\eta_e = 89\%$ |
| C = 50 | $\eta_e = 86\%$ |

In Fig. 163 the electrical efficiency is shown as a function of the load (Curve II.). The curve of electrical efficiency of this shunt machine rises rapidly, then remains nearly constant for loads between about $\frac{1}{2}$–$1\frac{1}{2}$ times the normal, and finally decreases gradually.

### (*b*) Series Machine.

Voltage, 100; current, 50; output, 5 K.W.

Total armature resistance: $0{\cdot}13\omega$ } hot.
Field resistance: $0{\cdot}09\omega$ }

In Fig. 164 Curve I. represents the characteristic of this machine.

The electrical efficiency is obtained by formula (24). Curve II. in Fig. 164 represents the efficiency as a function of the load. The difference between the latter curve and that of a shunt machine (see

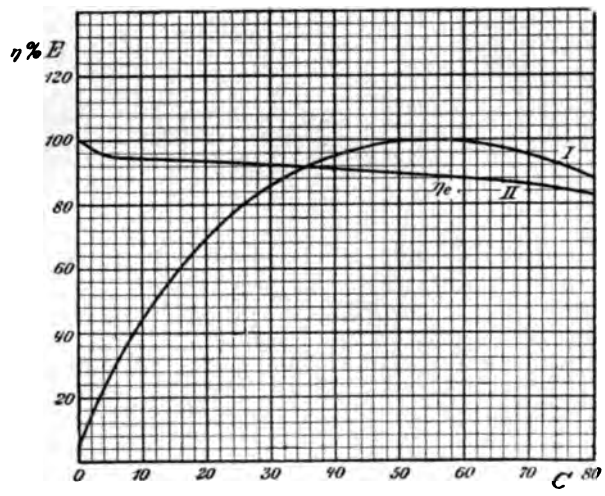



Fig. 164.

Fig. 163) is very marked. With the shunt machine the efficiency for C = 0 is 0, then rises gradually to a maximum, and falls again at high loads (overloads). On the other hand, with the series machine the efficiency is 100 per cent. at no-load, decreases gradually with increasing load, falls rapidly after the characteristic has reached the bend, and finally, if the machine were short-circuited, the efficiency would become zero.

(c) COMPOUND MACHINE.

Voltage, 250; current, 100 amps.; output, 25 K.W.
Total armature resistance: 0·125 $\omega$ hot.

$$\text{Field resistance} \begin{cases} \text{Shunt, } 50\omega \\ \text{Series, } 0{\cdot}005\omega \end{cases}$$

Curve I. in Fig. 165 is the external characteristic of the machine, and Curve II. represents the efficiency as a function of the load.

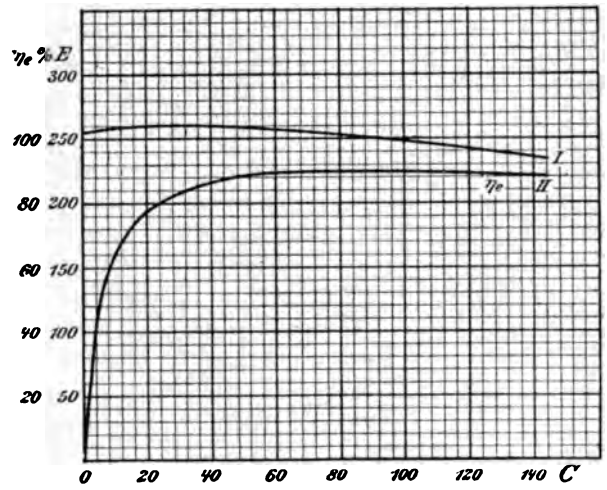



FIG. 165.

As the working of a compound machine corresponds more closely to that of a shunt than a series machine, the efficiency curve will likewise be similar.

## 2. The Total (Commercial) Efficiency

As enunciated in the introduction to this chapter, the total efficiency is the ratio of the energy delivered to that absorbed. Both energies must be expressed in the same units, *i.e.* either in Watts or in H.P. If we multiply this ratio by 100, we obtain the percentage efficiency; thus:

$$\eta\,(\%) = \frac{P_d}{P} \times 100$$

The total efficiency of a machine can hence be found by directly measuring or indirectly determining $P_d$ and $P_c$. One of these powers can in all cases be easily measured—with motors $P_c$, with generators $P_d$ (being electric energy in both cases). It can therefore be very accurately measured. The accuracy of this measurement will depend solely upon the accuracy of the instruments employed, and by using precision instruments an accuracy of $\frac{1}{4}$ per cent. may easily be obtained.

The measurement of the second energy, however, involves greater difficulties. With a motor the energy delivered, and with a generator that consumed, are mechanical. Since the two energies $P_d$ and $P_c$ to be measured are not of the same kind, and therefore requiring different types of instruments, certain inaccuracies are liable to be involved in the measurement of $\eta$, especially as with the ordinary instruments for measuring large mechanical energies a high degree of accuracy can hardly be obtained. The direct measurement of efficiency, *i.e.* by measuring the mechanical and electrical energies directly, is by no means a simple experiment.

Another method, however, can be resorted to. Obviously the energy consumed by a machine is equal to that delivered + the losses taking place in the machine; thus:

$$P_c = P_d + \text{total losses};$$

since

$$\eta = \frac{P_d}{P_c}$$

we have

$$\text{for a generator, } \eta = \frac{P_d}{P_d + \text{total losses}} \quad . \quad . \quad . \quad . \quad (26)$$

$$\text{for a motor, } \eta = \frac{P_c - \text{total losses}}{P_c} \quad . \quad . \quad . \quad . \quad (27)$$

For determining the efficiency in this way we must measure one of the energies—either the $P_d$ or $P_c$ as the case may be—and the losses arising in the machine. As the electric power can be easily and accurately measured, and since the measurement of the losses does not, as a rule, offer any difficulties, the indirect method is very frequently employed.

In some special cases the efficiency can be determined in a purely electrical manner. If two machines to be tested are alike in all respects, they may be connected together mechanically and electrically so that one running as a motor drives the other as a generator. If the machines work under the same conditions, their

efficiencies will be equal. The combined efficiency of such a set is equal to the ratio of the energy delivered by the generator to that consumed by the motor. From the combined efficiency of the set the efficiency of each of the machines can then be easily determined.

If the machine to be tested is a (rotating) continuous current transformer, the method becomes even simpler. Such a machine has generally one armature and two commutators. The efficiency of such a machine is determined by simply measuring both the primary and secondary voltages and currents.

According to what has been said, there are three different methods for determining the efficiency of a continuous current machine, viz. :—

(*a*) *The Direct or Braking Method.*—Both the electrical and the mechanical powers are measured directly, the latter by means of a brake, dynamometer, etc.

(*b*) *The Indirect Method.*—The electrical power is measured directly; then the total losses are determined, and from these two quantities the efficiency is computed.

(*c*) *The Direct Electrical Method.*—Both the energy delivered and the energy consumed are measured directly. Whilst the first two methods can be employed in any case, the last method is only applicable in a limited number of cases.

## 3. The Direct Method

The machine must run as a motor, and the power developed must be absorbed and measured by one of the braking arrangements described later. Under such a test motors will be working under the normal working conditions, but with generators the working conditions would be other than normal. Even if the speed and excitation were adjusted so as to be the same as during the normal running conditions, this method would not give as good results with dynamos as with motors.

Instead of absorbing the energy developed by the motor by means of a brake, a dynamo may be driven, the efficiency of which is known, for all speeds and loads. The efficiency of the combined set, and consequently also the efficiency of the machine to be tested, can then be found by electrical measurements only. This method is called the indirect braking method.

With dynamos the mechanical energy supplied can be measured by means of a dynamometer. If the electrical energy delivered by

the dynamo be then measured, the efficiency can be found without altering the normal working conditions of the dynamo.

Before dealing with the various methods, a description of the most important types of brakes, both mechanical and electrical, and a few types of transmission dynamometers, will be given.

## (*a*) Mechanical Brakes.

The principle of all mechanical brakes is the transformation of mechanical energy into heat (friction).

### *The Prony Brake.*

This is the oldest, and, despite its disadvantages, the most frequently used appliance. In its simplest form it consists of two wooden blocks which press by means of two hand-wheels against the brake pulley (see Fig. 166). If the latter rotates, the friction between the surface of the pulley and the wooden blocks tends to turn the brake in the direction of rotation. If one of the levers of the brake is loaded with a weight $P_1$ (which latter must be selected so that there is a state of balance between the force acting on the brake and the weight), then—

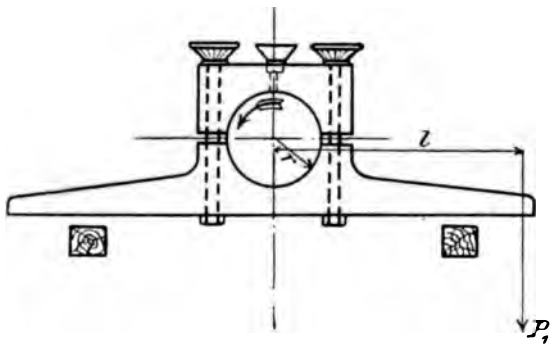



Fig. 166.

$$xr = P_1 l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

where $x$ is the tangential force on the radius $r$ of the brake pulley.

This equation is only correct if—

(*a*) The brake lever is exactly in a horizontal position, and

(*b*) The weight of the brake is balanced.

If the first condition is not fulfilled, equation (28) must be—

$$xr = P_1 l \cos a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

where $a$ stands for the angle which the brake lever makes with the horizontal.

To make sure that the weight of the lever is balanced, proceed as follows:—

Lift the top part of the brake by means of the two handwheels and insert a wedge between it and the pulley—exactly above the centre—so that the whole brake rests on this wedge. The brake can then be balanced by adding small pieces of metal to, or driving nails into, one or other of the levers as the case may be.

If $n$ is the number of revolutions of the motor per minute during the brake test, and $L_{B.H.P.}$ the load (output) in B.H.P., then—

$$L_{B.H.P.} = P_1 \cdot \frac{2\pi n l}{33000} \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

where $P_1$ is in pounds, and $l$ in feet.

If $l$ is made equal to 2·626 feet, then—

$$L_{B.H.P.} = \frac{nP_1}{2000} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

Should the mechanical power absorbed be considerable, a cooling of the brake will generally be necessary, and the simplest mode of cooling is by water. Such a cooling arrangement is indicated in Fig. 166.

In spite of the water cooling, a large local heating of the braking surfaces and a consequent great radiation of heat sometimes take place.

In such cases a sheet of iron should be placed between the motor and the brake, which simultaneously prevents the water splashing into the motor.

When working with the Prony brake proceed as follows:—

Make sure that the weight of the brake is balanced (see above), then turn the two handwheels, until the pulley cannot rotate freely, and open the water tap. The measurement can be made in two ways: Either determine the watt consumption of the motor for a certain output, or the output for a certain watt consumption. In the former case a weight ($P_1$) must be put on the lever corresponding to the required output; and the handwheels then tightened until the lever (with the weight) assumes again a horizontal position. The current, voltage, and speed should be read simultaneously.

If the output for a definite consumption of watts or a certain current is required, then the handwheels must be turned until the current reaches the requisite value. The lever will touch the upper or the lower stop, according as the weight $P_1$ is too small or too large. The weight $P_1$ must now be made larger or smaller until the lever is again in its horizontal position.

For a very fine adjustment the handwheels should be provided with thick indiarubber washers.

In its simplest form the Prony brake has the disadvantage, that a state of balance cannot be maintained for some time owing to the variable coefficient of friction. The lever consequently does not remain in its horizontal position when once adjusted, but swings up and down. This of course makes a quick and reliable measurement impossible. A constant load cannot be obtained without a frequent regulation and adjustment.

To avoid the former trouble Brauer and Wettler have made improvements in the Prony brake, which will be briefly referred to.

Fig. 167 shows a sketch of the arrangement devised by Brauer. The lever on the left is fixed to a spring balance, on which $P_1$ is read directly. The two wooden blocks are pressed on to the pulley by

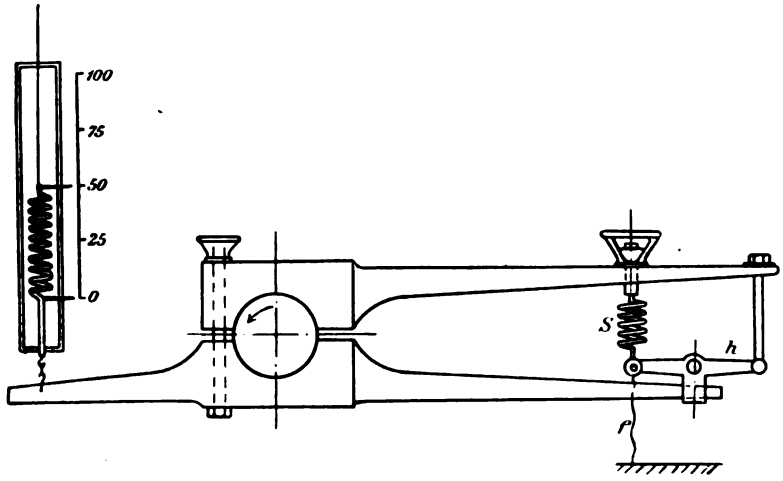



FIG. 167.

means of a spring S stretched by a handwheel when tightened. The spring S pulls the lever *h* downwards, and thus presses the wooden blocks against the pulley. If, owing to a disturbance of the state of balance, the whole brake tends to turn in the direction of the arrow, the wire *f* and spring S are stretched, and thus the pressure between the brake and the pulley is automatically reduced.

Another arrangement, shown in Fig. 168, is intended for a quick and simple manipulation of the Prony brake. In this arrangement a weight $P_1$ acts downwards on a lever (not shown in the figure) and a spring actuates the other lever upwards with a force $P_2$. Thus the two forces are additive. The lower end of the spring is connected with the brake lever, the upper end with a cord which passes over a

pulley. Two pointers, fixed at the ends of the spring, indicate its length at any moment. If no force acts on the brake, the lower pointer indicates 0. When the brake is applied, the spring must be adjusted by turning the pulley, so that the lower pointer stands at or swings about 0. When the lever is brought to a horizontal position by the above adjustment, the increase in length of the spring indicated by the upper pointer represents the force $P_2$, which can be read off directly in pounds by calibrating the spring.

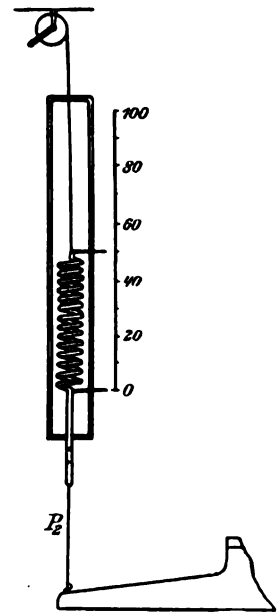


FIG. 168.

The spring in this arrangement mainly serves the purpose of avoiding the addition of small weights, and should be made to withstand a force of about 5 lbs. For greater forces, weights are placed on the second lever.

From the calibration curve of the spring employed, it will be seen that its elongations for the minimum and maximum loads are not proportional to the loads. In order to work on the part of the curve which is straight, it is best to load the spring, at the beginning of the measurement, with a small weight which evidently must be considered when calculating the output. With larger loads, this weight may be taken off or added to the other lever.

The calculation of the output differs from that of the ordinary Prony brake, inasmuch as there are two weights (or forces) to be considered.

Thus, for this arrangement we have—

$$L_{B.H.P.} = \frac{2\pi n}{33000}(P_1 l_1 + P_2 l_2) \quad . \quad . \quad . \quad . \quad . \quad (32)$$

If $l_1 = l_2 = l$, *i.e.* the two levers are of equal length—

$$L_{B.H.P.} = \frac{2\pi n}{33000}(P_1 + P_2)l \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

and if $l = 2{\cdot}626$ feet—

$$L_{B.H.P.} = \frac{n(P_1 + P_2)}{2000} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

Fig. 169 is an illustration of the Prony brake with the arrangement described.

Another improvement of the Prony brake with regard to automatic adjustment has been devised by F. Hubert * (shown in Figs. 170 and 171).

The general construction is shown in Fig. 170. One end of an iron band which is provided with wooden brake blocks, is fixed to the lever L, and the other end to a bolt Z working in a curved slot. On the free end of the lever L a weight P is suspended. The brake is adjusted as follows :—

Before applying the brake the bolt Z should be moved upwards as far as possible by means of the screw E, so that the pressure between

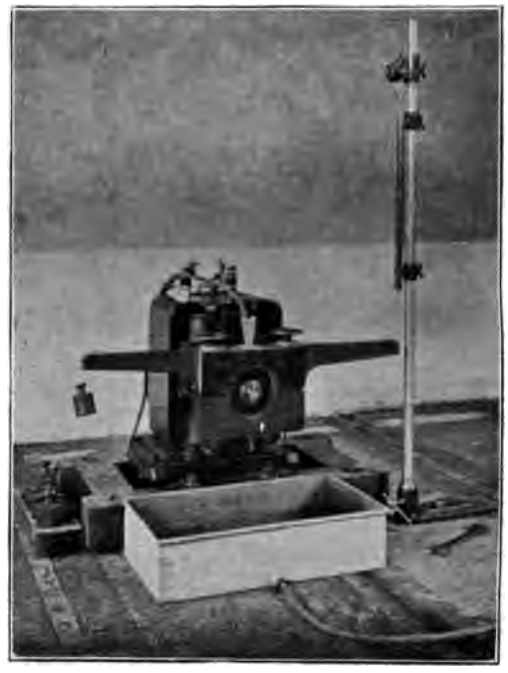


FIG. 169.

the wooden blocks and the pulley is very small. Then the iron tape B is released by turning the nut F until, with the rotation of the pulley in the direction of the arrow, the lever touches *first* the stop A and *then* the stop G. These two stops simply prevent a swinging of the lever L when the brake is wrongly adjusted.

* See *Electrotechnische Zeitschrift*, 1901, p. 339.

With the rotation of the pulley in the direction of the arrow, the lever may touch A either at the top or the bottom. The brake must then be adjusted by turning the screw E and thus moving the bolt Z upwards or downwards in the curved slot. If the lever touches A at the bottom (if the friction be too great), Z must be moved upwards. If the opposite is the case, Z must be moved downwards.

If the friction be too great, the lever will touch A from below and thus the pressure will be released so that the friction becomes smaller.

On the other hand, if the friction be too small, the lever will touch A from above. Thus the pressure of the wooden blocks, and consequently the friction, is increased, so that the variations of load are small.

The cooling is effected inside the pulley. Thus the wooden blocks

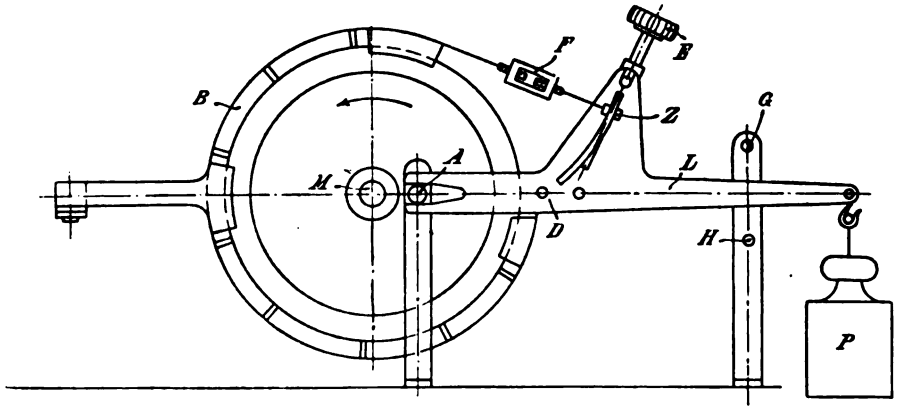



Fig. 170.

remain always dry, and consequently the coefficient of friction does not vary once the brake is adjusted.

Though with most brakes the direction of rotation of the motor is immaterial, this brake must always rotate in the direction indicated by the arrow, *i.e.* so that the weight is lifted, otherwise the brake will not act.

It is of advantage to put some grease on the pulley at the beginning of the test.

After starting the motor in the right direction, the weight can be adjusted to somewhat less than that corresponding to the normal load.

Water can now be admitted to the inner rim, the efflux adjusted according to the brake power.

The brake is finely adjusted by hand by turning the nut F to shorten the iron tape until the lever L, which should be loaded with

the normal weight P, leaves the stop H. The lever at the other end will touch the stop A either at the top or the bottom, according as the

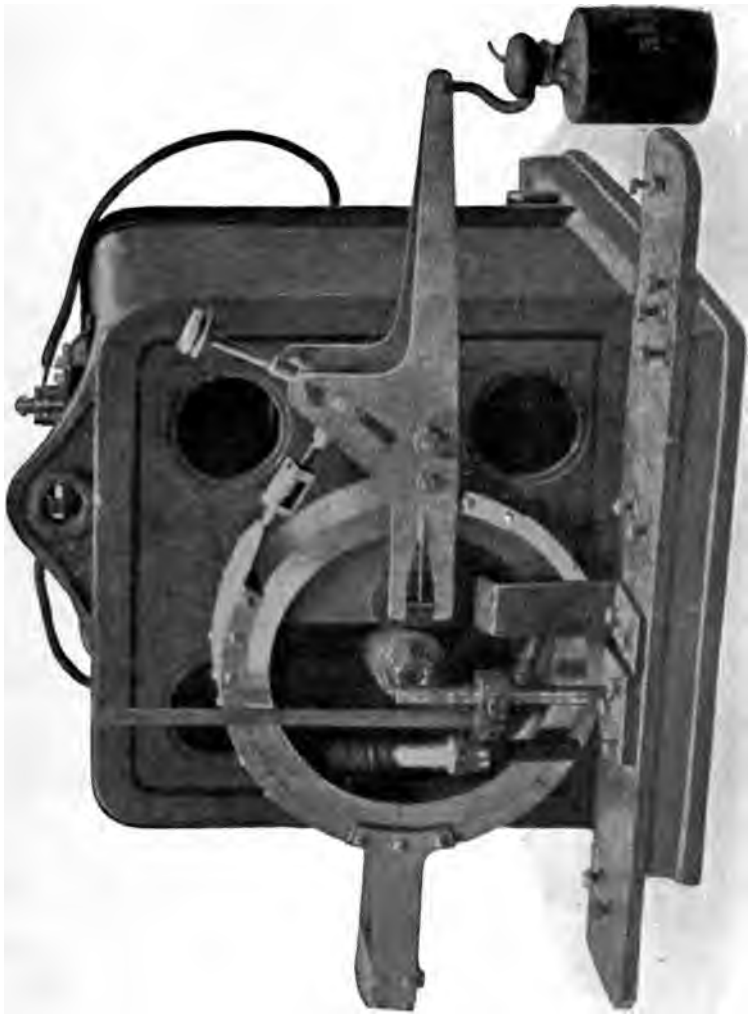


Fig. 171.

friction is too great or too small. By turning the handle E, *i.e.* by moving Z in the slot, the pressure of the blocks is regulated until the lever no longer touches A, *i.e.* when A is just in the centre of the slit.

For an exact measurement, it is essential that the centre of the brake pulley M, the slit at A, and the centre of the bolt on which the hook carrying the weight P is fixed, should all be exactly in line. Moreover, the stop A must be exactly in the centre of the slit. The distance between the centres of the pulley and the bolt on which the hook is suspended should be taken as the length of the lever.

During the time when readings are not recorded, an exact adjustment is unnecessary. If the brake has once been adjusted—after the pulley has been heated up and the water supply regulated—it requires no further attention.

Should the weight P be altered during the brake test, the load of the motor will be altered in nearly the same proportion, and only a very small adjustment of the bolt Z is required for a proper readjustment of the brake. Obviously the iron band must be shortened or lengthened according to the load, and care must be exercised that the lever L is always horizontal.

The amount of water required for cooling corresponds to the power absorbed by the brake, and the water tap should be opened sufficiently to prevent a considerable formation of steam.

When the test is finished and the motor requires to be stopped, the weight is taken off, the water tap closed, and the water gradually extracted from the interior of the pulley by moving the spoon gradually outwards. When all the water has been extracted, the motor may be stopped.

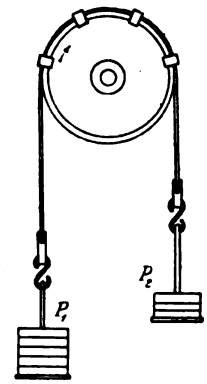


FIG. 172.

A very simple brake which is specially suitable for small motors, and has the advantage of cheapness, is depicted in Figs. 172–174. The simplest construction is shown in Fig. 172. A soft belt provided with several U-shaped metal clips is laid over the pulley, and on its ends hooks are fixed to which the weights $P_1$ and $P_2$ are suspended. $P_1$ is increased, or, what is equivalent, $P_2$ decreased, according to the load. The U-shaped clips serve the purpose of preventing the belt from slipping off the pulley. If there is a state of balance, then—

$$L_{B.H.P.} = \frac{2r\pi n}{33000} \cdot (P_1 - P_2). \quad . \quad . \quad . \quad . \quad . \quad (35)$$

This arrangement has the disadvantage that it requires a constant control. The brake shown in Fig. 173 is self-regulating—once adjusted the load is automatically kept constant. One half of the belt is provided with metal strips, and clips as before keep the belt over the

pulley. The belt is laid over the pulley as shown in Fig. 173, so that it touches only on a quarter of the circumference of the pulley. If due to any reason whatever the friction becomes too great, $P_1$ is lifted upwards, and the contact surface of the belt will be diminished. If, on the other hand, the friction becomes suddenly too small, $P_1$ falls, the contact surface is increased, and a state of balance is thus reached again.

The output is calculated from the formula (35).

The arrangement of such a brake with a spring balance is shown in Fig. 174. The brake force is here adjusted by increasing or decreasing

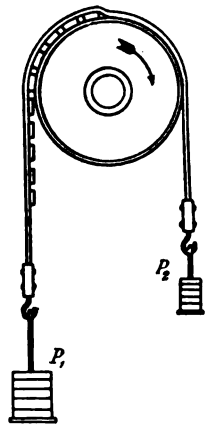



FIG. 173.

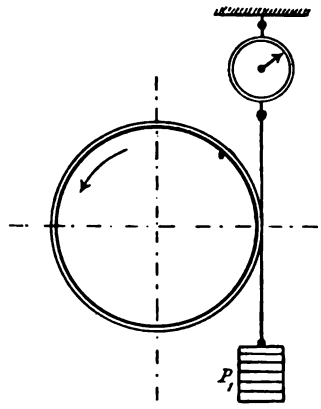



FIG. 174.

the weight $P_1$, and is read off directly on the spring balance. The latter should be frequently calibrated.

The output—

$$L_{B.H.P.} = \frac{2r\pi n}{33000} \cdot P_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

where $P_1$ is the pull read off on the spring balance.

The power transmitted from one machine to another can be measured by transmission-dynamometers. There are two main classes of transmission-dynamometers—those through which the power is transmitted by means of a shaft or coupling, and the others, through which the power is transmitted by a belt.

A few types of the latter class will be described.

The oldest and the best known is that of Hefner-Alteneck's. This dynamometer measures the difference in tension of the taut

(driving) and slack sides of the belt. If we call the former $T_1$ and the latter $T_2$, then the force acting on the circumference of the pulleys—

$$P = T_1 - T_2$$

This dynamometer consists of seven pulleys, of which the middle one is the largest (see Fig. 175) and is attached to the lever H. The latter can turn about the axis A. By an arrangement of levers H is connected with the pointer Z which carries a movable weight G. By means of G the weight of the whole movable system can be balanced. In the state of rest Z must point to the mark M.

The taut side of the belt $R_1$ presses the movable pulley downwards, and hence the pointer Z upwards. By turning the handle the

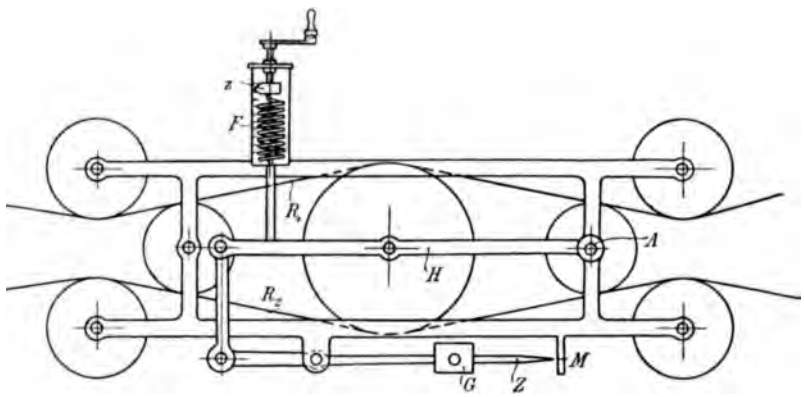



FIG. 175.

spring F is stretched, until Z is again at M, *i.e.* until the difference in pressure of $R_1$ and $R_2$ is balanced. The pointer $z$ indicates directly the pull in pounds required to balance the difference in pressure, namely, the force acting at the circumference of the pulleys. The dynamometer is calibrated empirically, and may be re-calibrated at times by suspending weights on the centre of the movable pulley.

Before using the instrument $z$ must be at the zero, and the weight G must be placed so that Z points to M.

The dynamometer described above can be used in connection with any belt-transmission of power, but with the dynamometers described below two belts are required, one of which must drive the dynamometer, whilst the other connects the dynamometer with the driven machine.

The principle of a toothed-wheel dynamometer is shown in Fig. 176. The toothed wheel $Z_1$, which is directly connected to the driven

pulley, is geared by means of a small wheel to another toothed wheel $Z_2$, which is directly connected to the driving pulley. $Z_1$ and $Z_2$ have equal diameters, and the small toothed wheel is movable within small limits in a vertical direction. This motion is trans-

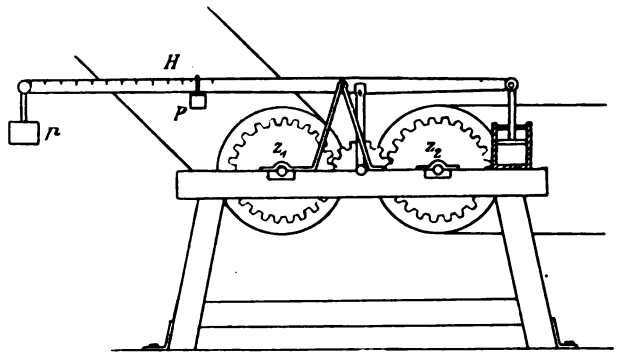



FIG. 176.

mitted to a lever H on which an adjustable weight $p$ is provided to balance the weight of the movable system.

When measuring the force transmitted by the belt, the direction of motion of the latter must be such that both $Z_1$ and $Z_2$ press the little toothed wheel downwards, viz. the lever H upwards. By moving P the lever is brought back to its horizontal position.

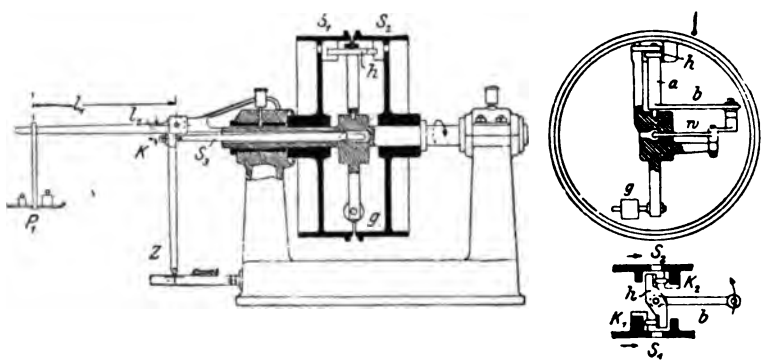



FIG. 177.

A Fischinger dynamometer is depicted in Fig. 177. The tangential force transmitted from one pulley ($S_1$) to the second ($S_2$) is obtained directly as follows:—

The force between the two pulleys is transmitted by means of

the lever $h$, the shaft $a$, the arm $b$, and the rod $S_3$ to a bent lever. One arm of the bent lever is provided with a pan for weights $P_1$. The weight of the movable system is balanced by means of the movable weight $g$.

If at a certain load the pointer Z is deflected from its zero position, it must be brought back again to zero by putting weights $P_1$ on the pan. The force T between the two pulleys is then balanced by the weights, thus—

$$T = Fl_2 = P_1 l_1$$

and—

$$F = \frac{P_1 l_1}{l_2}$$

thus—

$$L_{B.H.P.} = \frac{P_1 l_1}{l_2} \cdot \frac{2r\pi n}{33000} \quad . \quad . \quad . \quad . \quad . \quad . \quad (37)$$

and, if $\frac{l_1}{l_2} = 10$ (as is usually the case)—

$$L_{B.H.P.} = 0{\cdot}001904 r n P_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (38)$$

where $r$ is for the radius of each pulley, and $n$ their speed in revolutions per minute.

Even with the best designed mechanical brakes and dynamometers their accuracy is seldom more than $\pm 1$ per cent.; in most cases, however, it is still less.

For accurate measurements magnetic brakes have lately come into extensive use. The manipulation of these brakes is much simpler than with mechanical brakes, and the accuracy obtainable with some is as much as $\pm 0{\cdot}1$ per cent. at full load.

### (*b*) Magnetic or Eddy Current Brakes.

If a metallic disc rotates in a magnetic field, the eddy currents induced produce a certain resistance to rotation. This resistance corresponds to a retarding force acting at points immediately beneath the poles, and which tends to turn the latter in the direction of rotation of the disc. The retarding force is equal and opposite to the resistance which opposes the motion of the disc. The point of application of the force, both on the disc and on the magnets, cannot be easily found. It is therefore necessary that the magnetic system should be movable about the same axis as the disc; for only in this case will the moment of the force acting on the disc be equal to that acting on the magnets. One of the two parts, either the disc

or the magnetic system, must be coupled to the motor, and the other part must be movable about the axis within small limits.

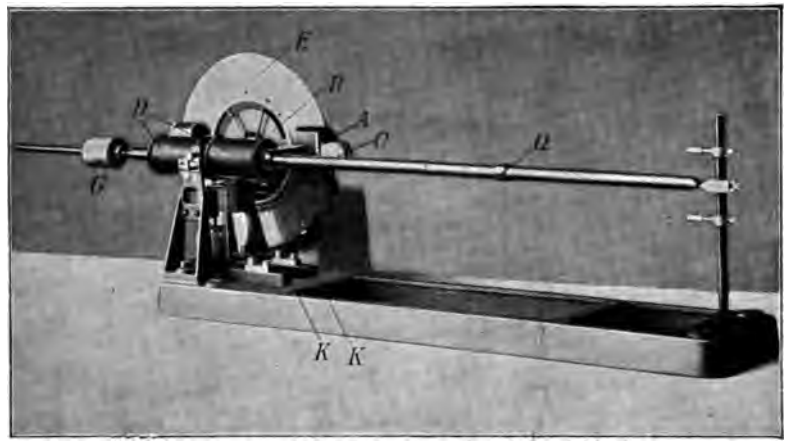



Fig. 178.

A brake constructed on this principle by Siemens and Halske is

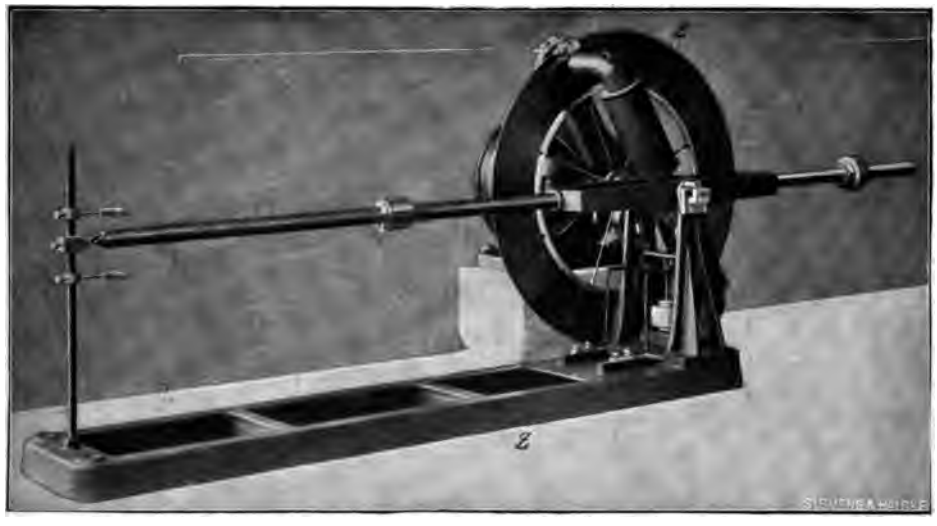



Fig. 179.

shown in Figs. 178 and 179. It consists essentially of a horse-shoe magnet A (Fig. 178), which is supported on knife edges, so that its

axis is in line with the geometrical axis of the motor. The magnetic path is closed by the yoke B, which is connected with A by brass brackets C, the distance between A and B being adjustable.

The magnet A is excited by the coils D, which are fixed on A; the ends of the coils dip into two mercury cups, from which wires lead to the fixed terminals K.

On one side of the field magnets is fixed a brass tube, which is provided with a scale, and on which a weight Q can be moved. On the other side of the magnets is a threaded shaft carrying a movable weight G, by means of which the movable system can be adjusted to a horizontal position.

Between the magnets A and the yoke B rotates a copper disc E, which is fixed to the motor shaft. At the free end of the brass rod, a stand provided with two stops prevents an excessive motion of the rod. A clamp on this stand indicates the horizontal position.

The adjustment of the brake is made as follows :—

Slide the weight Q to the zero point of the scale, and adjust the counter-weight G until the lever is horizontal. The magnets are then excited and the motor started. Eddy currents will be induced in the rotating disc, which will tend to turn the field magnets round, and thus deflect the brass lever from its horizontal position. The weight Q is moved outwards, until the lever assumes its horizontal position once more. The power supplied by the motor is then—

$$L_{B.H.P.} = \frac{2\pi b \,.\, nQ}{60 \,.\, 75} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (39)$$

where Q = weight in kilogrammes.
$b$ = distance of the weight from zero in metres.
$n$ = revolutions per minute.

For a certain weight Q the factor $\frac{2\pi Q}{60 \,.\, 75}$ is constant, so that—

$$L_{B.H.P.} = Cn \,.\, b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (40)$$

To make the calculation for the output as simple as possible, the weight Q is so selected that C becomes a round number.

For a fine adjustment of the brake power, the exciting current must be regulated very finely. A regulating resistance as shown in Fig. 25 should therefore be employed.

It may be mentioned that for exact measurements the power required to overcome the air resistance (of the copper disc) should be considered. This can be done by measuring first the energies consumed by the motor at certain speeds with and without the disc attached to the motor shaft. The difference of the energies consumed

is equal to the energy lost by air friction for that particular speed. In this way the friction loss can be determined for several speeds, and a curve be drawn showing this loss as a function of speed. The motor employed for this experiment should not be too small, otherwise the additional copper losses would have to be taken into consideration.

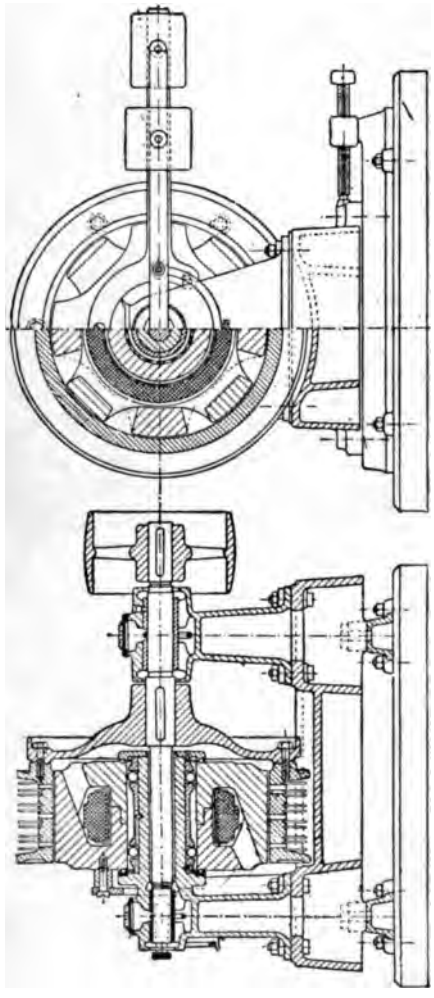


Fig. 180.

An accurate measurement of speed is obviously of great importance in this experiment. As this brake is mostly used for small motors, great care has to be taken that the energy consumed by the speed counter is not too great (see also Chapter V., p. 70).

*Rieter's Eddy Current Brake.*

The eddy current brake described above is constructed for small machines only, up to about 3 H.P.; the following (Rieter's) brake may be used for motors up to 50–60 H.P.

The construction of this brake becomes clear from the Figs. 180 and 181. It consists essentially of a multipolar magnetic field system, which, within small limits, is movable about its axis. The field is separately excited, and its windings are connected in series with a regulating resistance. On the shaft are a belt pulley or a coupling and an iron or steel ring, which latter encloses the magnetic field system. If this ring be rotated in the magnetic field, E.M.F.'s and consequently currents are induced in it. The strength

of these currents depends upon both the strength of the field (the excitation) and the speed of the iron ring. Thus the whole energy (with the exception of the energy lost due to air and bearing friction) absorbed by the brake is transformed into heat. The latter is produced in the rotating ring, whence it can easily be radiated; in order to increase the radiation of heat, a number of cooling ribs are arranged on the circumference of the ring.

At a constant speed the torque of the brake is directly proportional to the excitation. Hence by a fine regulation of the exciting current, the load of the motor can be adjusted very finely.

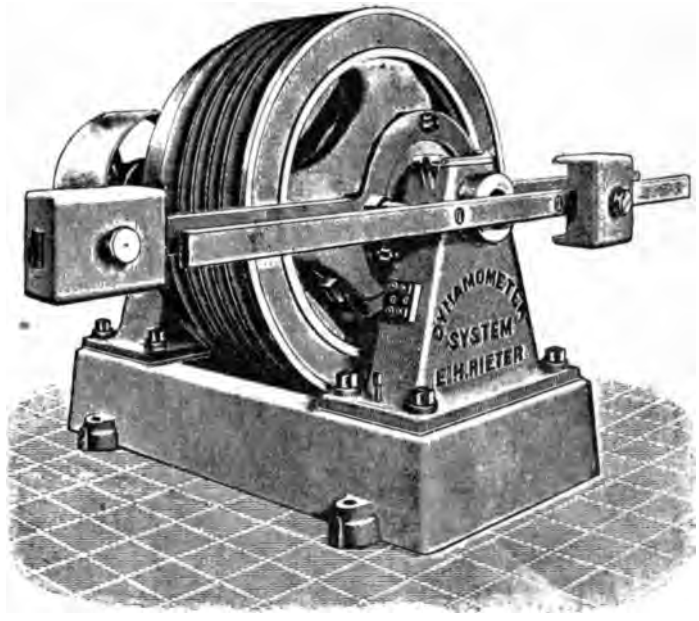



FIG. 181.

To balance the magnetic system two horizontal levers are attached; on one of the levers, possessing a scale, a weight can be moved from the middle towards the right or left until a state of balance of the movable system exists. To measure larger powers a larger weight is fixed on the second lever at a certain distance from the centre of the machine, thus giving a constant moment; the smaller weight being used for adjustment. Below the front lever a pointer and a scale is provided to indicate the position of equilibrium.

Let the power absorbed by air and bearing friction be $P_a$, and

the energy transformed into heat at a certain excitation be $P_h$, then the energy absorbed by the brake—

$$P_{B.H.P.} = P_a + P_h$$

Let $\Sigma(ml)$ be the turning moment of both levers in metre-kilogrammes; then—

$$P_h = \frac{\Sigma(ml)2\pi n}{60 . 75} \text{ in H.P.} \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

As the loss due to friction depends upon the speed only, it is best to determine this loss for a number of speeds, and plot it as a function of the speed.

According to Rieter, it is a linear function, *i.e.* a straight line. Hence for a given brake—

$$P_a = Kn \text{ in H.P.}$$

The coefficient K is given by Rieter for the brake described as 0·00143, so that—

$$P_{B.H.P.} = \frac{\Sigma(ml)2\pi n}{60 . 75} + \frac{n}{700} \quad . \quad . \quad . \quad . \quad . \quad . \quad (42)$$

The coefficient K should of course be determined for each brake.

In making a test with this brake proceed thus—

After the motor has been running with full load for some time, couple it to the brake; then start the motor again and excite the brake until the required load is reached. Then move the small weight according to the load until the state of balance is reached, *i.e.* until the pointer attached to the lever stands at the zero mark. If the motor voltage keeps constant, the state of balance will be maintained, and readings should be taken of the motor voltage, total current (*i.e.* armature + shunt currents) absorbed, and the position of the weights. Simultaneously the speed of the motor and the brake must be measured.

The efficiency of the motor will then be—

$$\eta = \frac{\left\{\frac{\Sigma(ml)2\pi n}{60 . 75} + P_a\right\}746}{E . C}$$

$$\eta = \frac{1{\cdot}041\Sigma(ml)n + 746P_a}{E . C} \quad . \quad . \quad . \quad . \quad . \quad (43)$$

This formula is only correct if the motor be directly coupled to the brake. If a belt is used, the loss due to slip must be considered.

If this loss be $x$ per cent. of the output, we have to multiply the efficiency obtained by the above formula by $\frac{100 + x}{100}$ in order to derive the correct efficiency.

The advantages of this and generally of all eddy current brakes are—

(*a*) Simple manipulation and great accuracy.

(*b*) No mechanical friction.

(*c*) No artificial cooling required.

The accuracy of eddy current brakes is very great. With the Siemens & Halske's brake an accuracy of $\pm \frac{1}{2}$ per cent. can easily be obtained. Fig. 182 shows the accuracy of Rieter's brake as a function of the power absorbed.

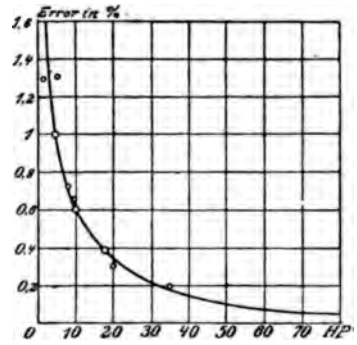



FIG. 182.

## 4. The Indirect Brake Method

Whereas the direct method is applicable to motors only, the indirect method has the advantage that the machine to be tested may run either as a generator or as a motor. In the indirect method the machine to be tested is coupled to an electric machine whose efficiency is known as a motor or generator for all loads. The auxiliary machine must work as a generator or motor according as the machine under test is a motor or generator. In either case the energies consumed and delivered by the combined set are electric, and can thus be easily and very accurately measured. Let $P_c$ be the energy consumed by the one, and $P_d$ that delivered by the other machine; then the combined efficiency—

$$\eta_c = \frac{P_d}{P_c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (44)$$

Further, let $\eta_a$ be the efficiency of the auxiliary machine, $\eta$ that of the machine under test; then—

$$\eta_c = \eta_a \cdot \eta$$

and—

$$\eta = \frac{\eta_c}{\eta_a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (45)$$

It is obviously important to know the exact efficiency of the auxiliary machine for all loads, if this method is to give reliable results. Moreover, it is necessary to know the efficiency of the auxiliary as a motor or generator for a great number of speeds in order to include the possible cases of speed of machines to be tested.

We shall first deal with the indirect braking method, and afterwards discuss the calibration of an auxiliary motor.

## Experiment No. XIX

*Determination of Efficiency of a Dynamo by the Indirect Braking Method.*

DIAGRAM OF CONNECTIONS.

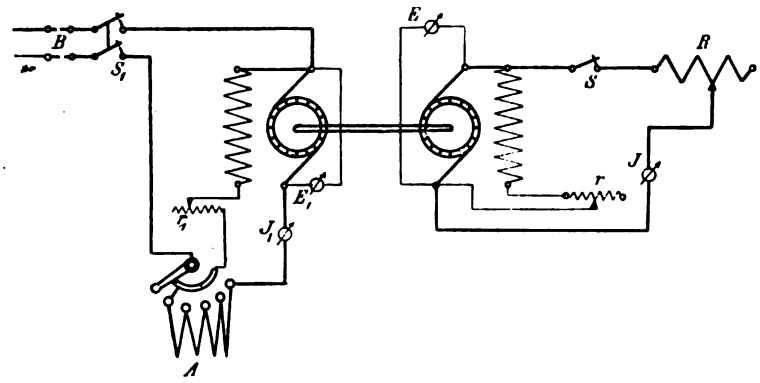



FIG. 183.

*Instruments and Apparatus required.*

(*a*) For the machine to be tested—
- J = Ammeter (about $\frac{3}{4}$ of the normal current).
- E = Voltmeter (normal voltage).
- R = Load resistance.
- $r$ = Shunt resistance.
- S = Main switch.

(*b*) For the auxiliary motor—
- $J_1$ = Ammeter.
- $E_1$ = Voltmeter.
- A = Starter.

$A_1$ = Combined starter and regulator (see note).
$r_1$ = Shunt regulator.
$S_1$ = Main switch.
B = Fuse.
One tachometer or speed counter.

NOTE.—If the normal speed of the dynamo is smaller than that of the auxiliary machine, the speed of the latter must be reduced by means of a regulating resistance. The size of this depends, of course, upon the amount of regulation required. A battery would be better still to use. Its voltage should be equal to the voltage for which the efficiency of the auxiliary machine has been determined for the respective speed. The auxiliary machine must, however, in any case be excited by the normal voltage.

If the normal speed of the dynamo is greater than that of the auxiliary motor, the terminal voltage of the latter must be increased or its field weakened. The former regulation is the better, as the latter can obviously only be chosen if the efficiency of the auxiliary machine has been determined with the weakened field.

*Experiment.*—The whole set should first be run for several hours with normal speed and full load, until a stationary state is reached with regard to the temperature of the armature and the bearings. If the dynamo and the auxiliary motor are approximately of the same size, both will reach their final temperature at the same time. But if the dynamo be small compared with the motor, the latter will not reach its final temperature even though the generator be fully loaded. In such a case the slight increase in efficiency (owing to the smaller loss in the armature in the cool as against that of the hot state) should be considered, assuming that the auxiliary machine has been calibrated in the hot state.

After running for some time the load is thrown off the dynamo. The motor voltage and the speed of the set are then adjusted, and the dynamo voltage (with open main circuit) is brought to the normal. The voltage of the motor and the current consumed are observed and recorded, after which the dynamo main circuit is closed and the load on the dynamo gradually increased. For various loads of the dynamo ($\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, and $\frac{5}{4}$ normal) read and record the current and voltage of both the dynamo and the motor. The speed must remain constant (or nearly so) throughout the experiment.

The efficiency of the dynamo is then easily deduced from the efficiency curve of the auxiliary motor and the total efficiency of the combined set.

## EXAMPLE XIX.

*Determination of the Efficiency of a* $2\frac{1}{2}$ *K.W. Dynamo for* 100 *Volts and* 1000 *Revolutions per Minute.*

As auxiliary motor a 5 B.H.P. motor was used; the efficiency curve of which for $n = 1000$, and the various loads is shown in Fig. 184.

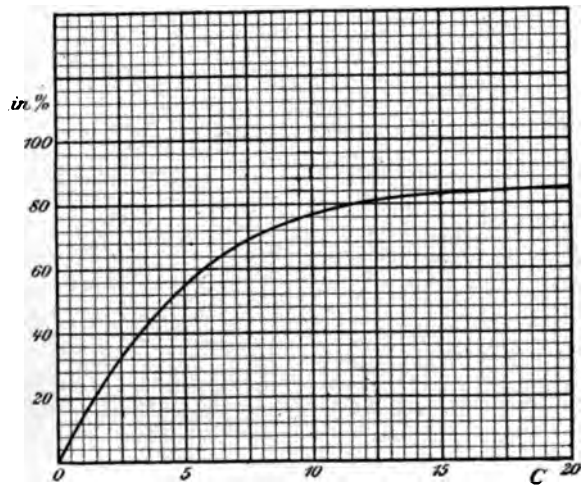



FIG. 184.

The dynamo voltage (100 volts) and that of the motor (220 volts) were kept constant. The results of the experiment were as follows:—

| Dynamo current. | Motor current. |
|---|---|
| 5 | 12·0 |
| 10 | 13·0 |
| 15 | 14·0 |
| 20 | 16·5 |
| 25 | 18·5 |

The combined efficiency—

$$\eta_c = \frac{\text{dynamo current}}{\text{motor current}} \cdot \frac{100}{220}$$

The following table comprises the dynamo currents, the combined efficiencies for these currents (found by the above formula), the efficiencies of the motor for the motor currents corresponding to the various dynamo currents (efficiencies taken from Fig. 184), and finally the dynamo efficiency calculated from the combined efficiency and the motor efficiency :—

| Dynamo current. | Combined efficiency, $\frac{C_d}{C_m} \cdot \frac{100}{220}$ | Motor (auxiliary) efficiency, $\eta_a$ | Dynamo efficiency, $\eta = \frac{\eta_c}{\eta_a}$ |
|---|---|---|---|
| 5 | 19·0 % | 80·0 % | 23·8 % |
| 10 | 35·0 % | 81·5 % | 43·0 % |
| 15 | 47·6 % | 82·2 % | 58·0 % |
| 20 | 55·0 % | 84·0 % | 65·5 % |
| 25 | 61·5 % | 84·5 % | 73·0 % |

In Fig. 185 the dynamo efficiency is plotted as a function of the load.

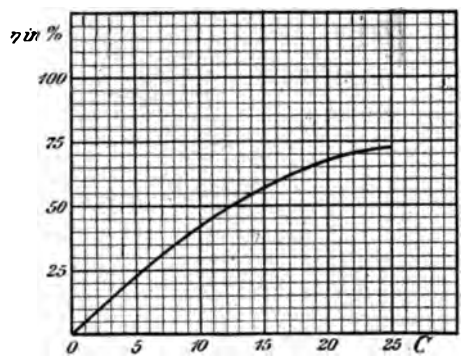



FIG. 185.

## 5. Calibration of an Auxiliary Motor

The calibration of an auxiliary motor, namely, the determination of its efficiency at different loads and speeds, can be made by any of the methods previously described.

If a sufficiently large eddy current brake is available, it is best to

employ it. However, the efficiency of the auxiliary as either a dynamo or motor can be obtained by the indirect method, viz. by the determination of losses. In practice this method is almost exclusively used for the calibration of an auxiliary motor. We are obliged to refer to the method here, though it will be described later on.

The calibration is conducted as follows: For all speeds, for which the auxiliary machine is to be calibrated, curves must be determined showing the relation of the exciting current and the load at constant voltage and speed (see Experiment No. XVIII.).

The curves thus obtained will enable us to determine the losses due to eddy currents and hysteresis at the different excitations corresponding to the different loads. The hysteresis losses vary with the 1·6th power of the excitation, but are directly proportional to the speed. Hence if we determine the hysteresis loss as a function of the excitation for a definite speed, we can from this curve easily find the loss for any other speed.

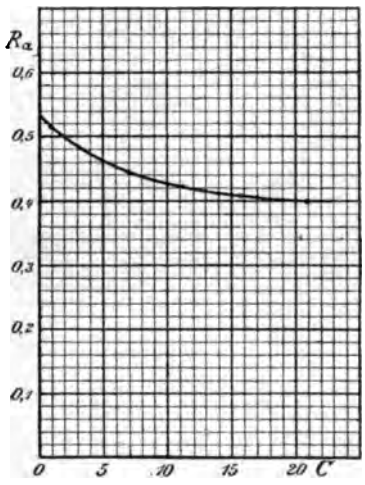


FIG. 186.

The eddy-current losses, on the other hand, vary with the square of the excitation and the square of the speed. We can either determine the eddy-current losses for various excitations and various speeds, or, from one curve showing the relation of the losses and the excitation at a particular speed, obtain those for the other speeds by calculation.

The mechanical losses depend, as we shall see later, upon the speed and the temperature of the bearings; the latter depending again upon the speed with which the machine runs. To determine accurately the friction losses, it will thus be necessary to make as many experiments as the number of speeds under consideration. For practical purposes it will be sufficient to make only one experiment to determine the friction loss as a function of the speed. The best selected speed at which the machine should run before the experiment is the normal.

Finally, the total armature resistance (hot) must be measured for different armature currents. From this resistance the armature loss can then be calculated for any load; if the field magnets are separately excited, the field loss need not be taken into account. In this case, however, the armature current only must be read, and not the total motor current.

From the individual losses thus determined the total losses, and from these, the efficiencies for the different loads and speeds, can be found. In the following a complete example is given for the calibration of an auxiliary machine both as a dynamo and as a motor.

The machine used was a 5 B.H.P. motor by the British Thomson-Houston Co., for 1000 revolutions per minute and 220 volts.

Firstly, the armature resistance was measured in the hot state. Fig. 186 shows the armature resistance as a function of the armature current. The field resistance was 312·5$\omega$ (hot).

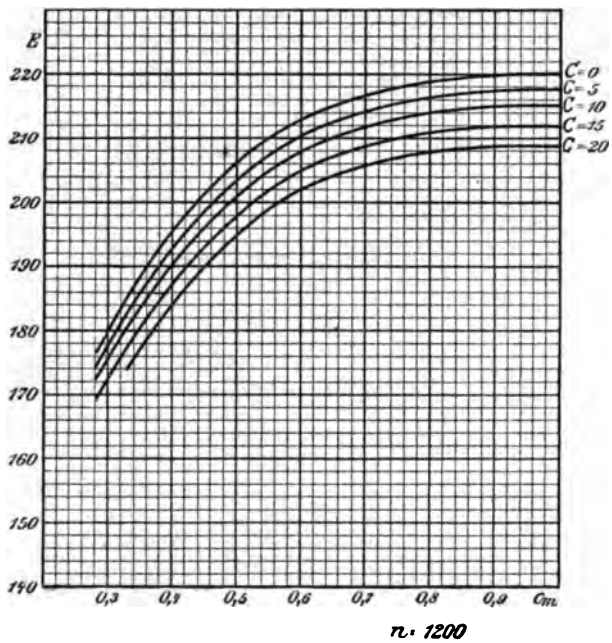



FIG. 187.

Next the load characteristics of the machine (running as dynamo) were determined for C = 0, 5, 10, 15, and 20 amps. (see Fig. 187). The experiments were made at one speed ($n$ = 1200), since (within certain limits) at constant excitation the voltage can be assumed to be directly proportional to the speed.

The determination of the friction, hysteresis, and eddy-current losses was made by the methods described in the next chapter. The results of these experiments are shown in the Figs. 188 and 189.

Fig. 188 shows the individual losses as a function of the speed at a constant excitation of $c_m = 0{\cdot}7$, whilst the curves in Fig. 189 represent the losses due to hysteresis and eddy currents at a constant speed ($n = 1200$) as a function of the excitation. The friction losses are of course independent of the excitation. The curves in Fig. 189 have been determined from the curves of Figs. 187 and 188 in the following manner:—

For $c_m = 0{\cdot}7$ and $n = 1200$ we find from Fig. 188 the hysteresis

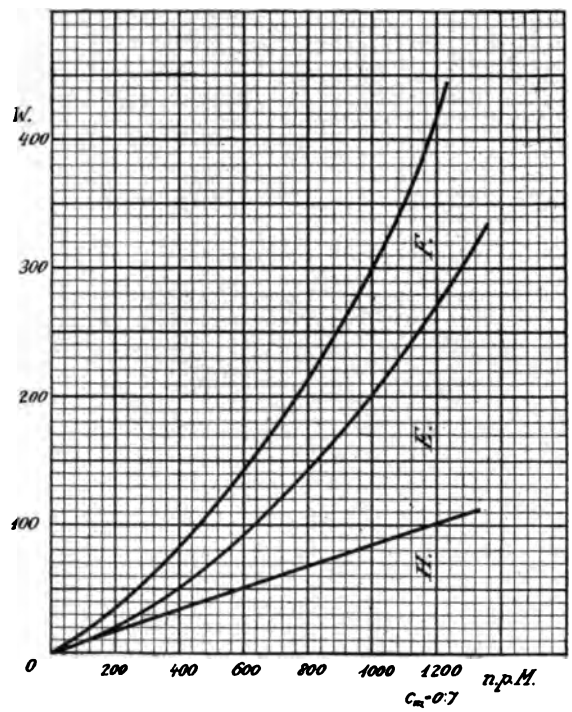



Fig. 188.

loss to be 100 watts, and the eddy-current loss 170 watts. These two points are plotted in Fig. 189. For any other excitation and the same speed the hysteresis loss is proportional to the 1·6th power, and the eddy-current loss to the 2nd power of the excitation, or (as the speed is constant) the square of the E.M.F. We must therefore find from the magnetization curve (Fig. 187, C = 0) the voltage corresponding to the given excitation, and for any other excitation increase or

decrease the losses in the ratio of the 1·6th or 2nd power respectively.

As an example: For $c_m = 0{\cdot}7$ and $n = 1200$, the hysteresis loss $= 100$, the eddy-current loss $= 170$ watts. The losses for the same speed, but $c_m = 0{\cdot}4$, are obtained by noting the E.M.F.'s corresponding to $c_m = 0{\cdot}7$ and $c_m = 0{\cdot}4$ (from the magnetization curve for $n = 1200$). These E.M.F.'s are (see Fig. 187) 216·5 and 195·5 respectively. Hence the hysteresis loss for $c_m = 0{\cdot}4$.

$$P_H = 100 \cdot \frac{195{\cdot}5^{1{\cdot}6}}{216{\cdot}5^{1{\cdot}6}} = \text{about 87 watts}$$

and the eddy-current loss for the same excitation ($c_m = 0{\cdot}4$)

$$P_e = 170 \cdot \frac{195{\cdot}5^2}{216{\cdot}5^2} = \text{about 140 watts}$$

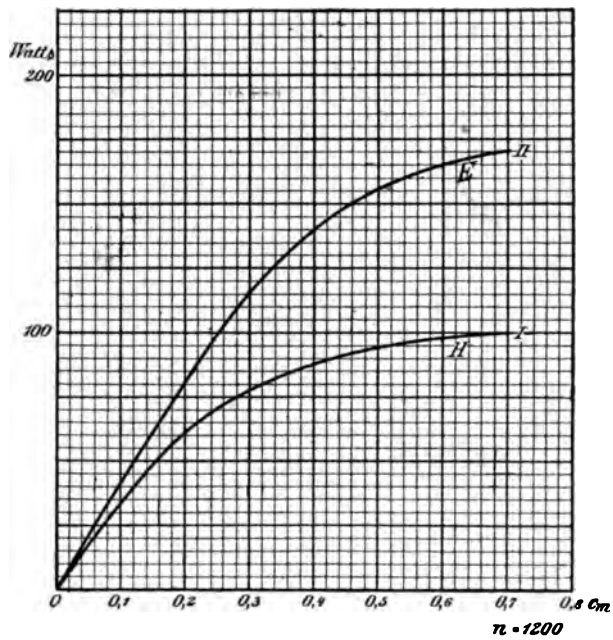



FIG. 189.

In the same way the hysteresis and eddy-current losses can be found for any other excitation. Evidently a few values are sufficient to plot the respective curves.

From the curves I. and II. in Fig. 189 two groups of curves for

various speeds can be deduced, one group for the hysteresis and the

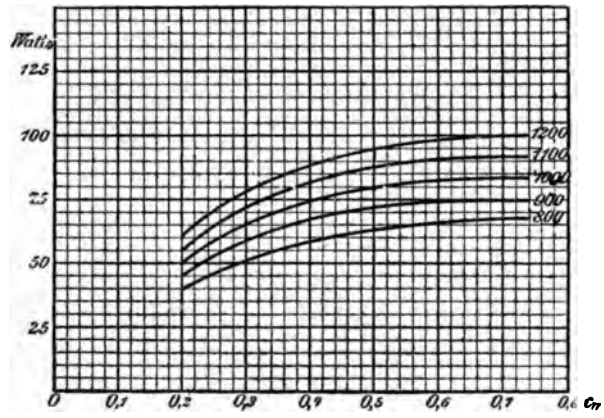



FIG. 190.

other for the eddy-current losses. In Fig. 190 curves are given showing the hysteresis losses as functions of the excitation for

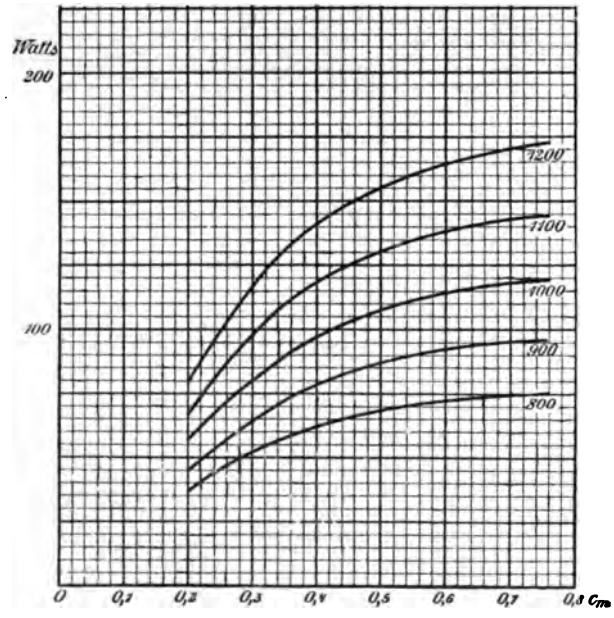



FIG. 191.

$n$ = 800, 900, 1000, 1100, and 1200. In Fig. 191 similar curves are

given for the eddy-current losses. These curves are calculated by the formulæ :

$$P_{h1} = P_h \frac{n_1}{n}$$

and

$$P_{e_1} = P_e \frac{n_1^2}{n^2}$$

From the curves thus determined the efficiency of this machine may be found for any speed, excitation, and load, whether running as a dynamo or a motor. All we require is to measure the voltage, current, and speed of the machine, and determine the individual losses from the various curves. From the sum of these losses and the output (or the watt-consumption) of the machine the efficiency is found by calculation.

The following examples show the calculations of efficiency of the auxiliary machine as a dynamo and a motor :—

### Example A.

The machine ran as a dynamo with $n = 1200$ revolutions per minute. Readings of the instruments were as follows :—

$$C_a = 15 \text{ amps.}$$
$$c_m = 0{\cdot}6 \text{ amps.}$$
$$E = 205 \text{ volts}$$

The machine was separately excited.

From Fig. 186 the armature resistance $r_a$ for 15 amps. is found to be $0{\cdot}41\omega$. Thus the ohmic loss in the armature—

$$P_0 = C_a^2 r_a' = \text{about } 92 \text{ watts}$$

From Fig. 188 the loss due to friction for $n = 1200$ is about 150 watts.

The hysteresis loss (see Fig. 190) is 98 watts, the eddy-current loss (Fig. 191) 165 watts. The sum of all losses (excluding the loss due to excitation) is therefore : $92 + 150 + 98 + 165 =$ **505** watts.

The output delivered is $205 \times 15 = 3075$ watts.

The efficiency—

$$\eta = \frac{3075}{3075 + 505} = \text{about } 86\,\%$$

Considering the loss in the field magnets ($205 \times 0{\cdot}6 = 123$ watts), we have—

$$\eta = \frac{3075}{3075 + 628} = \text{about } 83\,\%$$

EXAMPLE B.

The machine worked as a dynamo with $n = 800$ revolutions per minute.

$$C_a = 5 \text{ amps.}$$
$$c_m = 0{\cdot}46 \text{ amps.}$$
$$E = 130 \text{ volts}$$

The armature resistance for $C_a = 5$ is $0{\cdot}46\omega$; thus the ohmic loss in the armature—

$$P_0 = 5^2 \times 0{\cdot}46 = 11{\cdot}5 \text{ watts}$$

The loss due to friction for $n = 800$ is 70 watts, the hysteresis loss for the same speed and $c_m = 0{\cdot}46$ is 62 watts, the eddy-current loss 66 watts; thus the sum of all losses (excluding the loss due to excitation) = about 210 watts. The output of the dynamo was $5 \times 130 = 650$ watts; thus—

$$\eta = \frac{650}{860} = \text{about } 75{\cdot}5\,\%$$

Considering the loss due to excitation ( $= 130 \times 0{\cdot}46 =$ about 60 watts), we have—

$$\eta = \frac{650}{920} = \text{about } 70{\cdot}5\,\%$$

EXAMPLE C.

The machine ran as a motor with a speed of $n = 1000$ revolutions per minute.

$$C_a = 15 \text{ amps.}$$
$$c_m = 0{\cdot}74 \text{ amps.}$$
$$E = 220 \text{ volts}$$

The individual losses are—

| | |
|---|---|
| Ohmic loss (armature) ... ... | 92 watts |
| Friction loss ... ... ... | 100 „ |
| Hysteresis loss (Fig. 190) ... ... | 84 „ |
| Eddy currents ... ... ... | 119 „ |
| Total (excluding excitation) ... | 395 watts |

Hence—

$$\eta = \frac{220 \times 15 - 395}{220 \times 15} = \text{about } 88\%$$

The loss due to excitation is $231 \times 0{\cdot}74 = 172$ watts; hence, considering this loss—

$$\eta = \frac{2733}{3300} = \text{about } 82{\cdot}5\%$$

## 6. The Indirect Method

The indirect method for the determination of efficiency consists, as already mentioned, of measuring the total losses taking place in a machine. From these losses, which we will call $L_t$, and the (electrical) energy delivered or consumed, the efficiency can be calculated as follows:—

With a generator: The output delivered is EC, the losses $L_t$, hence the energy consumed must be $EC + L_t$. The efficiency—

$$\eta = \frac{EC}{EC + L_t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (46)$$

With a motor the energy consumed is EC, the losses $L_t$, hence the energy delivered is $EC - L^t$. The efficiency—

$$\eta = \frac{EC - L_t}{EC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (47)$$

For a better conception of the various methods of finding the individual losses, we shall now discuss the seat and approximate values of the same.

The losses arising in continuous current machines may be separated into three groups, viz.—

(*a*) Ohmic Losses.
(*b*) Magnetic Losses.
(*c*) Mechanical Losses.

### (*a*) Ohmic Losses.

These losses are due to the ohmic resistance of the armature and the field windings. The loss in the armature winding is directly proportional to the square of the armature current (*i.e.* to the load). It also increases with the increasing temperature of the machine,

namely, with the time of working, unless a stationary state with regard to temperature has been reached.

The loss due to contact resistance is not directly proportional to the square of the current—as a matter of fact, the contact resistance decreases with increasing current. The same refers to the losses arising in the carbon brushes, as long as their final temperature has not been attained; as the temperature coefficient of carbon is negative, its resistance decreases with increasing temperature.

With regard to the loss arising in the field windings, from what has been stated in the discussion of electrical efficiency (see p. 164), it will depend solely upon the type of machine (whether shunt, series, or compound). In a shunt machine the loss due to excitation is almost independent of the load. It increases but very little with increasing load, owing to the necessary increase of the shunt current to maintain a constant voltage. Since the resistance of the field winding remains practically constant, the $c^2r$ loss in it will gradually increase with the load. With machines having a shunt regulator, the loss arising in the latter must of course also be considered. We shall see in a later chapter how this is obtained.

Shunt motors generally possess no shunt regulators. Thus with these the loss due to excitation is independent of the load.

With series machines the loss due to excitation is proportional to the square of the load. In this case also the losses taking place in the regulating resistances (which may be arranged in parallel to the field windings) must be duly considered.

With compound machines this loss is combined of the losses in the series and shunt windings. The above remarks are applicable to these losses respectively.

The amounts of the losses in the armature and field windings depend upon the size, type, etc., of the machine. The following table gives an average value of the respective losses for standard machines of different sizes :—

| Output of machine in K.W. | Ohmic loss in armature and brushes in percentage of the total output, about— | Loss due to excitation in percentage of the output, about— |
|---|---|---|
| $\frac{1}{10}$–1 | 15–10 | 12–8 |
| 1–10 | 10–7 | 8–6 |
| 10–50 | 7–4 | 6–4 |
| 50–100 | 4–2 | 4–2 |
| above 500 | below 2 | below 2 |

### (*b*) Magnetic Losses.

These comprise the

Loss due to hysteresis in the armature core (including the teeth).

Loss due to eddy currents in the armature core, armature boss, pole-shoes, armature winding, and commutator bars.

*Hysteresis.*—If an iron bar be magnetized up to a certain degree by passing a current round it, and then the current be broken, the bar will not lose its magnetism entirely, but will retain a residual amount according to the quality of the iron. If the magnetism of the bar is now reversed (by reversing the current) a definite number of ampere-turns (*i.e.* a definite amount of reverse current) will be first required to bring the magnetism of the bar to zero. By increasing the current beyond this amount, the magnetism of the bar will increase. This procedure is repeated at each reversal of magnetism of the bar, and is graphically represented by Fig. 192. In this particular case 150 ampere turns per centimetre length of the bar are required to produce an induction of 15,000 lines per square centimetre. If the exciting current is broken (zero ampere-turns), the induction will still be 8000 lines per square centimetre. To destroy this magnetism (and thus prepare the bar for the reversal of magnetism), 20 ampere-turns in the opposite direction are required; and to produce an induction of 15,000 in the opposite direction, 130 additional ampere-turns are requisite.

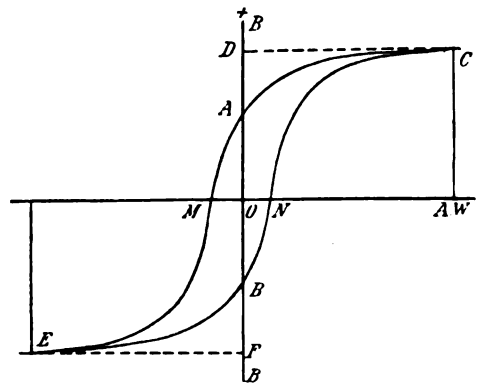


Fig. 192.

The cause of this phenomenon is the so-called coercive force. This force prevents the smallest iron particles, which may be imagined as molecular magnets, from adjusting themselves automatically in the direction of the magnetic force. When all or the majority of these molecular magnets are adjusted in the direction of the magnetic force, the same coercive force will prevent them returning to their original (neutral) position. To overcome this resistance, which arises at each magnetization and demagnetization, a definite

amount of work is required, which, according to Steinmetz, is called Hysteresis.

With regard to the amount of this work, consider what takes place in producing a magnetic field. A certain amount of energy is expended which is liberated when the field disappears. That this energy is restored, we see in the case of an iron core provided with a coil, where an E.M.F. or current due to self-induction is produced when the circuit is broken, *i.e.* when the core is demagnetized. The work done by this current obviously corresponds to the energy which is set free owing to the demagnetization of the iron core. If we magnetize the iron core to B = 15,000 (Fig. 192), we must expend a certain amount of energy proportional to the area BDC. If the molecular magnets were all freely movable, viz. if no coercive force exists, the whole energy expended in magnetization would be liberated on demagnetization. But, owing to the lagging of the magnetization (*i.e.* hysteresis), the amount of energy set free corresponds only to the area ACD; the remaining amount of energy corresponding to ACB is transformed into heat. At one complete cycle of induction the amount of energy lost due to hysteresis will correspond to the loop EACB. This area was shown by Hopkinson to be equal to that of a parallelogram of sides MN and DF. MN corresponds to double the coercive force, and DF to double the maximum induction. Hence it is self-evident that the hysteresis loss during one cycle or one period depends upon the maximum induction reached and the coercive force, namely—upon the specific quality of the iron. The loss will further be directly proportional to the volume of the iron.

Steinmetz found that the hysteresis loss (in absolute units) is

$$P_h = \eta B^{1.6} v \,.\, p \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (48)$$

where $\eta$ = hysteresis coefficient.*
B = maximum induction.
$v$ = volume of iron in cubic centimetres.
$p$ = periodicity per second.

From the above discussion, two conditions must be fulfilled in order to measure the hysteresis loss in machines; viz.:—

(1) The induction in the armature, and thus the excitation, must be the normal.

(2) The machine must run with the correct periodicity, *i.e.* with the correct speed.

* Wrought iron, $\eta$ = about 0·002.
Cast iron, $\eta$ = „ 0·017.
Cast steel, $\eta$ = „ 0·0027.

Special stress must be laid upon the first condition, as the hysteresis loss depends on the 1·6th power of the induction (excitation) as against the first power of the periodicity (speed)—the second condition.

It must be mentioned that the above discussion of hysteresis loss is only correct for magnetization by an alternating current; with an iron cylinder rotating in a magnetic field the matter is somewhat different, as is evident from Fig. 193. With a rotation of the cylinder the molecular magnets will tend to assume consecutively the positions indicated by $A_1$, $A_2$, $A_3$, and $A_4$; that is, they will also tend to rotate. To overcome the resistance which is offered to the rotation of these molecular magnets a certain amount of work is required. In contrast to the hysteresis described before this loss is called "rotating hysteresis."

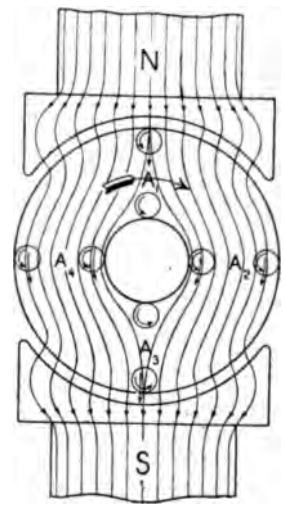


FIG. 193.

The hysteresis loss produced by the rotating field is, according to Bailey, somewhat smaller at low inductions than the loss produced by an alternating field. It reaches a maximum at B = 16,000, and falls rapidly at still higher inductions (B = 20,000).

With regard to the amount of hysteresis loss in armature cores this varies according to the size and construction of the machine. In designing a machine a compromise is generally made between the hysteresis loss and the amount of iron employed in the armature. The smaller the amount of iron, the lighter and cheaper the machine will be, but the armature induction and the hysteresis loss (notwithstanding the smaller volume of iron) will be greater. With slotted armatures the hysteresis loss in the teeth forms sometimes a considerable part of the total hysteresis loss, especially when the teeth are long and thin. Hence the hysteresis loss in toothed armatures will generally be larger than in smooth armatures. With small armatures, which are usually threaded directly on the shaft, the percentage hysteresis loss is generally small, owing to the comparatively large cross-sectional area of the core (small induction).

*Eddy Currents.*—The E.M.F. induced in a metal cylinder rotating in a magnetic field depends upon the induction at the particular point and its speed. With a perfectly homogeneous field and a small radial dimension of the metal cylinder, the E.M.F. induced will be the same in all parts of the rotating body; hence currents are not

produced. However, if one of the above conditions is not fulfilled, namely, if either the field is not homogeneous or the speeds of the various points of the rotating body are different (which would for instance be the case if the thickness of the cylinder were considerable), E.M.F.'s of different values would be induced. Currents will result whose values depend on the ohmic resistance encountered. As the resistance of such a cylinder will be very small, the currents thus produced will, notwithstanding the small potential difference, be very large. According to the law of Conservation of Energy, these currents oppose the motion of the cylinder, thus consuming power and involving a loss. These currents, termed eddy or Foucault currents, have further the disadvantage that they heat the rotating body very considerably.

Without entering further into the subject, it may be stated that the amount of eddy-current loss depends upon the quality of the metal, its volume, the square of the maximum induction, and the square of the periodicity (speed). As in the experimental determination of the hysteresis loss, we must also in the case of the determination of eddy-current loss take care to adjust both the speed and the excitation to their correct values. The fact that the hysteresis loss is proportional to the speed, and the eddy-current loss to the second power of the speed, gives us a means of separating these losses from each other.

The eddy-current loss depends on another influencing factor which requires some explanation.

The direction of the E.M.F.'s induced in a rotating metal body is at right angles to the direction of the lines of force and the direction of motion. In the case of a cylinder this direction will be axial and the axial resistance of a solid cylinder is very small, thus the loss due to eddy currents and the overheating of the cylinder would be excessive. To avoid this the core is built up of a number of thin iron stampings, laminated at right angles to the axis of the cylinder. The iron sheets are further electrically insulated from each other by means of paper, varnish, or similar materials. The effect of this lamination is twofold: Firstly, the induced E.M.F.'s, and consequently their active differences—by which the eddy currents are produced—will be smaller the thinner the stampings are made. Secondly, the axial resistance of the thin sheets will be considerably higher than that of the solid cylinder. The result is a considerable diminution of the eddy-current losses and the consequent heating.

The lamination of a metal core has thus a very great influence on the amount of the eddy-current losses. The latter are directly proportional to the square of the thickness of a single stamping.

The formula for the determination of the eddy-current losses is as follows :—

$$P_e \text{ (in absolute units)} = K_e\left(\delta \frac{p}{100} \cdot \frac{B_{max.}}{1000}\right)^2 v \quad . \quad . \quad (49)$$

where $\delta$ = thickness of the stampings in millimetres,
$K_e$ = a constant.

The eddy currents in continuous current machines include those:

(1) *In the Armature Core.*

Besides the above-mentioned eddy currents in the armature core, eddy currents are produced in the solid parts of the armature boss, unless they are out of the influence of the magnetic field. With ring armatures the conductors in the interior of the core produce a stationary magnetic field, the axis of which coincides with the neutral zone, and whose intensity obviously increases with increasing load. In this field the inner parts of the armature boss rotate; the losses thus resulting will be larger if the boss is made of iron, and smaller if it consists of brass, gun-metal, etc.

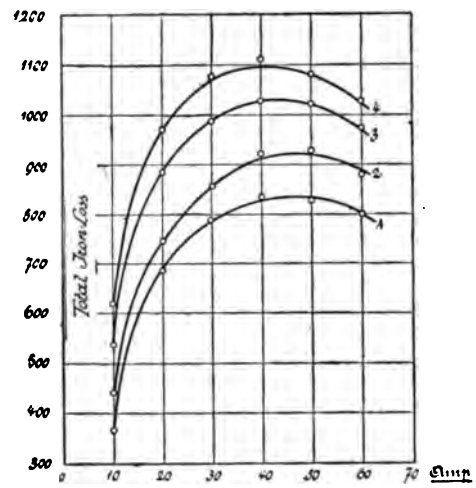



FIG. 194.

A further loss is due to the final turning up of the armature core and filing out or otherwise finishing the slots. Unless the tools used are very sharp, a conducting surface is formed, which will give rise to eddy-current losses. These may under certain circumstances be quite considerable, as shown by the curves in Fig. 194. These curves have been taken from an armature in the different states of manufacture, viz.—

Curve 1, after the stamping of the sheets.

Curve 2, after the slots have been made true by drawing a tool through them.

Curve 3, after the slots have been filed.

### (2) *In the Armature Winding.*

If a thin copper conductor moves in a homogeneous magnetic field, no eddy currents are produced in it, as has been explained before. Assuming the field under the pole-shoes of a continuous current machine to be homogeneous—an assumption which is practically correct if the machine is running light—no eddy currents will be produced in the armature winding as long as it is within or out of the field. When entering or leaving the field, however, the inductions at the various points of the armature conductor are different (see Fig. 195), so that eddy currents will be produced. To diminish these, the conductors are also subdivided, and frequently cables are employed instead of solid wires. Oxidation between the single strands forms a sufficient insulation.

Fig. 195.

When a machine is loaded, the originally homogeneous field is distorted, as we learned in the introduction to Chapter VII. (see Fig. 110), and the conductors will no longer move in a homogeneous field, consequently the eddy-current losses in the armature winding will be larger at full than at no-load. It may further be pointed out that the eddy-current loss in the armature winding depends on the shape of the conductors, the depth and width of the slots, etc.

### (3) *Eddy Currents in the Pole-shoes.*

These eddy currents arise in machines with slotted armatures only, and are caused by the irregular distribution of the lines of force above the teeth (see Fig. 196). The field is strongest above the teeth, and weakest above the slots. These points of alternate strong and weak induction rotate together with the armature, thus inducing eddy currents in the pole-shoes. The strength of these currents depends upon the width and depth of the slots, and upon the size of the air gap. These losses, which as a rule are small, can be further reduced by laminating the pole-shoes. They are experimentally determined together with the eddy currents in the armature.

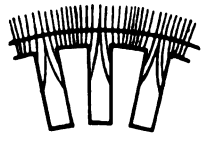


Fig. 196.

(4) *Eddy Currents in the Commutator Segments.*

The current leaving or entering through a brush produces a stationary field, though not homogeneous. The commutator bars, when rotating, cut this magnetic field so that eddy currents result, which are larger the thicker the commutator bars are. Hence with machines having a few bars only, *i.e.* with machines for small voltages, this loss will be greater than with machines for normal voltages. The overheating of the commutator bars due to eddy currents is with small voltage machines sometimes considerably larger than that caused by the brush friction and the $C^2R$ loss of the brush contact.

Finally, the hysteresis losses in the pole-shoes and the losses taking place in uninsulated or insufficiently insulated armature bolts may be here referred to.

Since with slotted armatures we have points of higher and lower inductions rotating with the armature, periodical variations of the intensity of magnetization will take place in the inner parts of the pole-shoes, thus involving a hysteresis loss in these parts, which will of course be very small.

With many, especially very large armatures, bolts keep the stampings together. In these bolts alternating voltages are induced, since they rotate in a magnetic field. If the bolts are not properly insulated from the end plates, closed circuits are formed through which flow strong alternating currents. The loss caused by these depends mainly upon the situation of the bolts in the magnetic field.

(*c*) MECHANICAL LOSSES.

These comprise:
(1) Losses due to friction in bearings.
(2) Losses due to brush friction.
(3) Losses due to air friction (windage).

(1) *Losses due to Friction in Bearings.*

The friction of the shaft in the bearings of the machine involves a loss, the amount of which depends upon
(i) The pressure.
(ii) The speed.
(iii) The lubrication.
(iv) The temperatue of the bearing.

Tower and Dettmar have from experiments enunciated three laws of bearing friction, which are of importance in the experimental

determination of friction losses, as they show under what circumstances and conditions the respective experiments must be made.

These laws are—

(1) With constant temperature of the bearing and constant peripheral speed of the shaft, the coefficient of friction is inversely proportional to the specific pressure, and consequently the friction loss is independent of the pressure, unless the latter exceeds about 550 lbs. per square inch.

From this law we see that within the limits specified the bearing pressure need not at all be considered when determining the friction loss—that is, there is no difference whether the machine is running light or loaded, or the belt be slack or tight. There are consequently no additional friction losses. The limit of 550 lbs. per square inch is hardly ever exceeded with good machines.

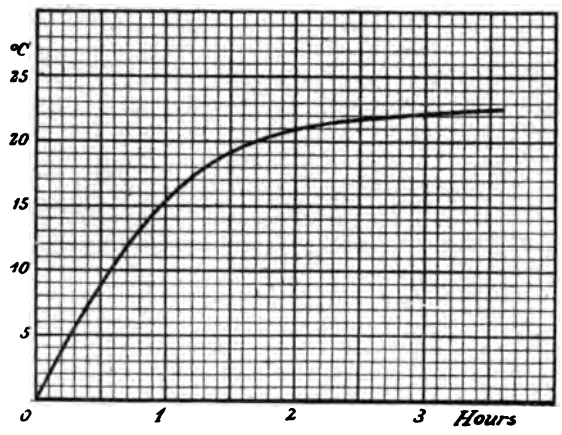



Fig. 197.

(2) With constant specific pressure and constant speed of the shaft, the coefficient of friction is inversely proportional to the temperature of bearing; consequently the friction loss is inversely proportional to the temperature.

All bearings become heated with a machine run until a final temperature is reached. The period of time in which this temperature is reached depends upon the size and construction of the bearing, and varies between 3 and 6 hours and even more. The limit of the overheating depends, as will be shown later on, essentially on the speed of the shaft, *i.e.* on the speed of the machine.

The curve in Fig. 197 represents the increase in the bearing temperature of an 8 K.W. machine at constant speed as a function of time. Fig. 198 represents the increase in the temperature as a function of speed of the shaft. From the second friction law we see that before determining the friction loss, the machine must have been running until the bearing temperature has reached its maximum. Further, during this run, the speed must be normal or at any rate

equal to the speed for which the friction loss is required, so that the bearing can reach the correct final temperature.

(3) With a constant bearing temperature and constant specific pressure, the coefficient of friction increases almost as the square root of the speed of the shaft; thus the friction loss increases with about the 1·5th power of the speed.

The frictionloss further depends upon the type of lubrication and the lubricating material. In determining the friction loss the same lubricating material should therefore be used as during normal working.

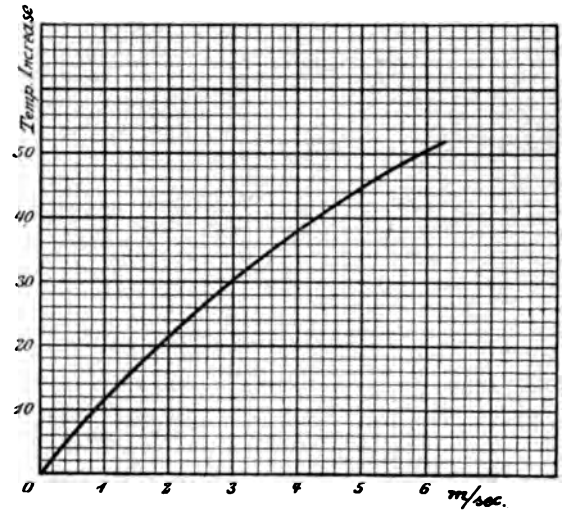



FIG. 198.

(2) *Losses due to Brush Friction.*

The friction between the brushes and commutator involves a loss depending upon the coefficient of friction, the peripheral speed of the commutator, and the brush pressure. The coefficient of friction varies with the quality of the commutator surface (whether rough or smooth) and the contact of the brushes on the commutator.

In measuring the loss due to brush friction, care should be taken that:

(1) The machine has been fully loaded for several hours;

(2) The contact between the brushes and commutator be good; and

(3) The normal pressure be put on the brushes.

(3) *Losses due to Air Friction.*

This loss, which is only of importance with very good ventilated armatures, cannot separately be determined. It depends upon the construction of the armature and winding and the third power of the speed.

Further losses in continuous current machines are involved by

the irregular distribution of the current beneath the brushes and by any sparking. These losses are very small with good machines. The discussion of them would exceed the scope of this book.

As the individual losses arising in continuous current machines have been amply discussed, we can proceed next to deal with the determination of efficiency by the indirect method.

## Experiment No. XX

*Determination of Efficiency of a Shunt Machine by the Indirect Method.*

DIAGRAM OF CONNECTIONS.

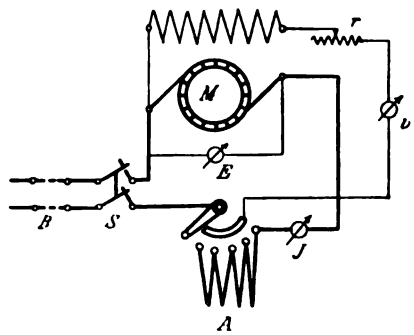



FIG. 199.

*Instruments and Apparatus required.*

J = Main ammeter (for about 15–20 per cent. of normal current).
E = Voltmeter (normal voltage).
$i$ = Shunt ammeter.
A = Starter and regulator.
$r$ = Shunt resistance.
S = Main switch.
B = Fuse.
One tachometer.

*Note.*—The voltage available should be larger than the normal voltage of the machine.

*Experiment.*—With this method the energy consumed by the armature when running light as a motor with normal excitation and normal speed is measured. This energy represents the sum of the magnetic and mechanical losses, the former depending upon the speed and excitation and the latter upon the speed only. If the ohmic losses in the armature and field windings are added to the above losses, the total losses and hence the efficiency can be computed.

The experiment consists therefore of two parts, viz.—

(1) Resistance measurement of armature and field windings.

(2) Measurement of the no-load losses.

(1) The total armature resistance must be measured by one of the methods described in Chapter II. The armature loss of course is to be determined for its maximum temperature. If the overheating corresponding to the normal load be known, the armature resistance may be measured when cold; in which case the resistance when hot must be calculated by the formula given. This method is, however, not very accurate for machines with carbon brushes, as the contact resistance is hardly affected by the temperature whilst the carbon brush resistance itself decreases with increasing temperature. It is therefore better to measure the armature resistance after a full-load machine run of several hours (according to its size). We shall see that this is essential in the determination of the no-load losses.

If $r_a$ is the total resistance of the armature (when hot), the ohmic loss

$$P_0 = C_a^2 r_a$$

where $C_a$ stands for the total armature current, noting that for a generator

$$\text{armature current} = \text{main current} + \text{shunt current}$$

and for a motor

$$\text{armature current} = \text{main current} - \text{shunt current}$$

If the efficiency is only to be determined for a particular load, say full load, then it will be sufficient to measure the armature resistance for this current. But usually the efficiency is determined for various loads; in which case the armature resistance must be measured for the various armature currents and plotted as in Fig. 200. From this curve another may be plotted showing the ohmic loss in the armature as a function of the load.

The resistance of the field may be measured when either hot or cold, but must be in either case referred to the hot state. The

measurement of field resistance is described on p. 48. With motors, possessing no shunt regulator, the loss due to excitation—

$$P_m = c_m^2 r_m$$

where $c_m$ stands for the shunt current.

The separate determination of the shunt resistance is, however, not essential. The loss can be also found from—

$$P_m = Ec_m$$

where E is the voltage applied to the shunt terminals. Thus, after a

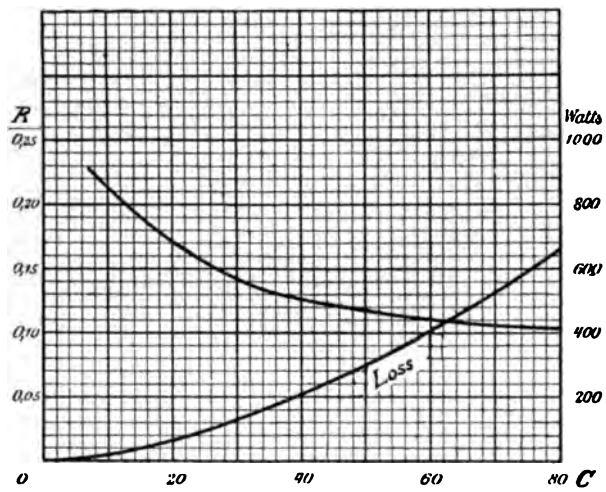



FIG. 200.

run of several hours, the voltage and shunt current need only be observed.

With generators and motors, provided with a shunt regulator, the loss in the latter must be taken into account. This may be done as follows: Run the machine with normal speed and vary the load from zero up to the maximum for which the efficiency is required. Adjust the shunt regulator for all the loads so that the voltage of the dynamo (or the speed of the motor) remains constant, and record the armature and shunt currents. The curve in Fig. 201 shows these currents plotted against each together. From this curve and the known constant voltage another curve can be calculated showing the relation of the total excitation loss (shunt winding + shunt resistance) and the load.

(2) As has been already stated, the no-load loss represents the sum of all the magnetic and mechanical losses. If the induction (excitation) and speed are the normal, all the conditions for correct experimental determination of the magnetic losses are fulfilled. With the mechanical losses, however, this is not the case. The bearing friction does not only depend upon the speed of the machine, but also upon the temperature of the bearing; which latter again depends upon the speed of the shaft. It is hence necessary that the machine shall have been running for several hours with normal speed. When the bearings have reached their maximum temperature, the experiment can be made as follows:—

First, determine the relation between exciting current and load (see Fig. 201). Then connect the machine as shown in Fig. 199, and run it light as a motor. Regulate the shunt current by means

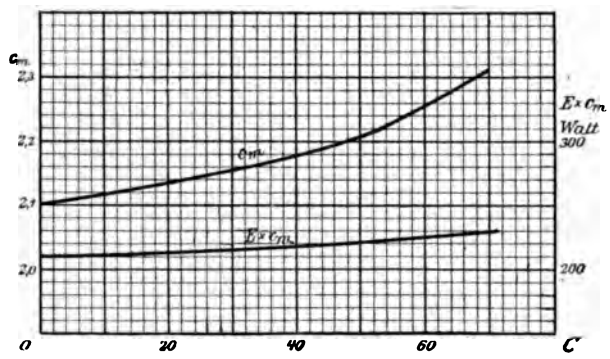



FIG. 201.

of $r$ and the speed by means of the regulating resistance to their respective normal values, and after a few minutes read the main current and the terminal voltage.

For ordinary measurements this will suffice; but if very accurate results are wanted, we must take into account that these losses do not remain constant at all loads. The excitation of a generator will be greater at full than at no-load—if the terminal voltage is kept constant—thus the magnetic losses will vary with varying load. With motors (which are not provided with shunt regulators for keeping the speed constant), the excitation is the same for all loads; but on the other hand the speed varies with varying load, thus causing a variation in the mechanical and magnetic losses. If this variation is to be considered, proceed as follows:—

Determine—in the case of a generator—the no-load losses for

various exciting currents corresponding to the various loads. These exciting currents are derived from Fig. 201. In determining the no-load losses for all these exciting currents the speed must be kept constant by means of the main regulating resistance. A curve can then be drawn showing the sum of the magnetic and mechanical losses as a function of the exciting currents (or the corresponding loads).

Proceed similarly for a motor: Obtain the curve showing the relation of the speed and load, *i.e.* the motor characteristic (see Experiment No. XIII.); then determine the no-load losses for all speeds corresponding to the various loads (excitation being kept constant). The speed, evidently, is varied by means of the main regulating resistance. From these two curves a third can be drawn representing the no-load losses as a function of the various speeds (or the corresponding loads).

In measuring the no-load losses it must be remembered that not all the energy measured is spent in overcoming the magnetic and mechanical resistances; but a small part is expended in overcoming the ohmic resistance of the armature, thus the $C_0^2 r_a$ loss is to be deducted from the no-load watts ($C_0$ = no-load current).

When all the individual losses have been determined a curve can be drawn representing the total losses as a function of the load, and from the formulæ given on p. 168 the efficiency can be found for all loads.

Before working out an example, let us shortly recapitulate the points in performing the experiment.

(1) Long run of the machine with full load; duration according to size.

(2) Measurement of total armature resistance with currents from about zero to the maximum load current.

(3) Measurement of field resistance. Unnecessary with machines possessing a shunt regulator, but in which case they require a

(4) Determination of the exciting current as a function of the load.

(5) For accurate experiments with motors—determination of the external characteristic.

(6) Measurement of the no-load watts for ordinary cases at normal excitation and speed; but for very accurate measurements—

(*a*) For generators—no-load watts for constant speed and various excitations as given by experiment (4) above.

(*b*) For motors—no-load watts for constant excitation and various speeds, as given by experiment (5).

In the following are given two examples for the determination of efficiency by the indirect method, for a motor and dynamo respectively:—

## Example XX.

*Determination of Efficiency of a Shunt Machine by the Indirect Method.*

Machine, No. 2267. Type and maker: Kolben, Prague. Number of poles, 4.

Voltage, 220; output, 15 H.P.; revolutions per minute, 880.

Instruments used—Weston Volt-ammeter, No. 1236.

The resistance of the armature when hot was first measured. The results are given in the following table:—

| $e_1$ Armature stationary. | $e_2$ Armature turned clockwise. | $e_3$ Armature turned counter-clockwise. | $C_a$ | $r_1$ | $r_2$ | $r_3$ |
|---|---|---|---|---|---|---|
| 1·8 | 2·4 | 2·8 | 12·7 | 0·142 | 0·188 | 0·22 |
| 2·32 | 2·9 | 3·3 | 16·3 | 0·142 | 0·178 | 0·202 |
| 3·16 | 3·7 | 4·1 | 25·0 | 0·127 | 0·148 | 0·164 |
| 4·2 | 4·6 | 5·0 | 34·5 | 0·121 | 0·133 | 0·145 |
| 4·54 | 5·14 | 5·34 | 39·0 | 0·117 | 0·132 | 0·137 |
| 8·3 | — | — | 87·0 | 0·95 | — | — |

The respective curves are given in Fig. 202, viz.—

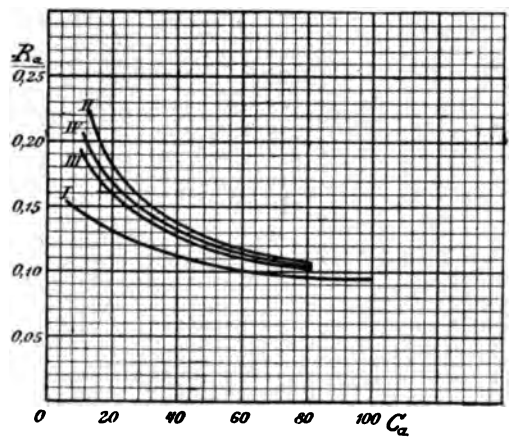



Fig. 202.

Curve I. with the armature stationary.
Curve II. „ „ turned clockwise.
Curve III. „ „ „ counter-clockwise.
Curve IV. the average of II. and III.

The resistance of the field windings (hot) was 220ω.

A few points of the external characteristic were then found. With constant terminal voltage (220) the results were as follows:—

| | | | | | | |
|---|---|---|---|---|---|---|
| C = | 4·85 | 15 | 30 | 50 | 75 | 85 |
| $n$ = | 880 | 870 | 860 | 842 | 805 | 792 |

This characteristic is plotted in Fig. 203.

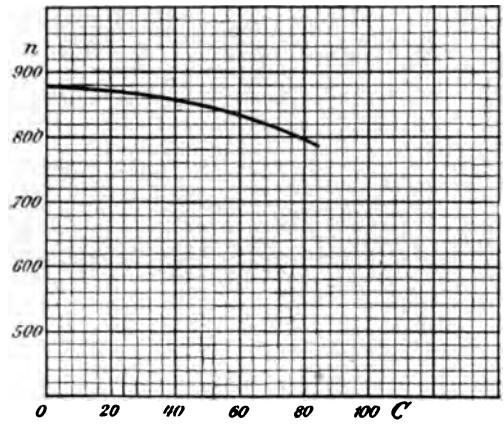



FIG. 203.

The machine was then excited with the normal exciting current of $\frac{220}{220}$ = 1 amp., and the no-load watts measured for various speeds ($n$ = 415 up to $n$ = 888).

The following results were obtained:—

*Determination of No-load Watts.*

| | | | | | | |
|---|---|---|---|---|---|---|
| Exciting current $c_m$ | = | 1 amp. | | | | |
| Terminal voltage E | = | 222 | 182 | 168 | 156 | 106 |
| Armature current $C_a$ | = | 4·9 | 4·7 | 4·5 | 4·45 | 4·35 |
| $EC_a - C_a^2 r_a$ | = | 1082 | 850 | 751 | 691 | 457 |
| Revolutions per minute | = | 888 | 726 | 662 | 620 | 415 |

The results are plotted in Fig. 204.

From these experiments the total losses can then be plotted as a function of the load. Curve I. in Fig. 205 represents the ohmic loss; Curve II. the loss due to excitation; and Curve III. the no-load losses as a function of the load. To plot the no-load losses we must first

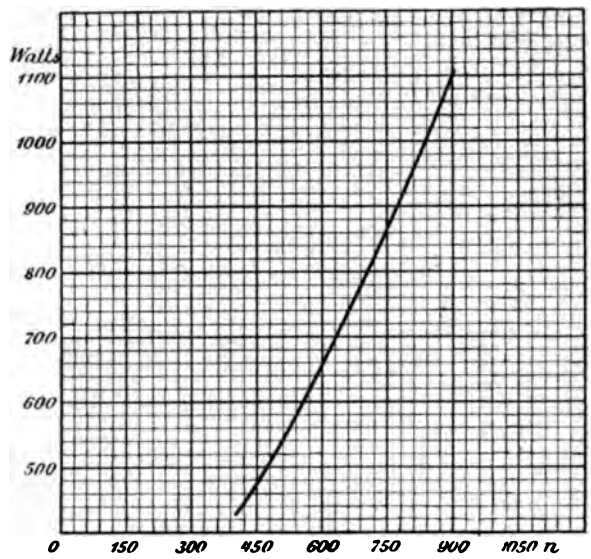



FIG. 204.

obtain from Fig. 203 the speed corresponding to a certain load, and then from Fig. 204 the no-load loss corresponding to this speed. Lastly, Curve IV. in Fig. 205 represents the total losses of the machine. From these the efficiency is calculated.

We have, for instance, for

$$C = 20$$

$$\eta = \frac{20 \,.\, 220 - 1340}{20 \,.\, 220} = \text{about } 70\,\%$$

$$C = 40$$

$$\eta = \frac{40 \,.\, 220 - 1480}{40 \,.\, 220} = \text{about } 83{\cdot}5\,\%$$

$$C = 60$$

$$\eta = \frac{60 \,.\, 220 - 1640}{60 \,.\, 220} = \text{about } 87\,\%$$

$$C = 80$$

$$\eta = \frac{80 . 220 - 1830}{80 . 220} = \text{about } 89{\cdot}5\ \%$$

Etc.

In Fig. 205 Curve V. represents the efficiency as a function of the load.

To determine the efficiency of the same machine as a dynamo, it

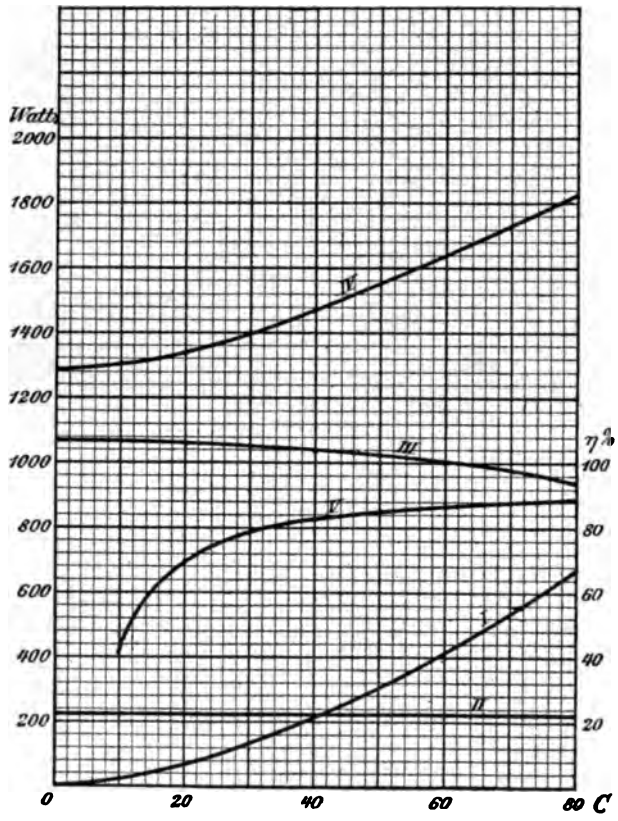



FIG. 205.

was separately excited, run with 880 revolutions, and the exciting current determined as a function of the load (see Fig. 206, Curve I.). The no-load losses were next measured for the various excitations (from $c_m = 1{\cdot}04$ to $1{\cdot}32$). Curve II. shows these losses as a function of the loads corresponding to the various exciting currents.

If, as before, we plot the separate losses as functions of the load, we get Fig. 207. In this figure,

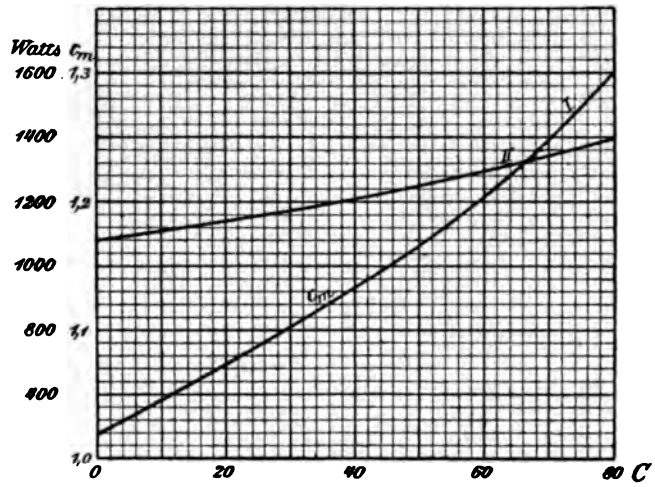



FIG. 206.

Curve I. represents the ohmic loss in the armature.
Curve II. „ loss due to excitation.
Curve III. „ no-load losses.
Curve IV. „ the sum of the losses I.–III.

Curve II. is obtained from

$$P_m = c_m^2 r_m$$

where $r_m = 220\omega$.

From Curve IV. the efficiency for any load may be found. For instance, for

$$C = 20$$

$$\eta = \frac{20 \times 220}{20 \times 220 + 1440} = \text{about } 75\,\%$$

$$C = 40$$

$$\eta = \frac{40 \times 220}{40 \times 220 + 1700} = \text{about } 84\,\%$$

$$C = 60$$

$$\eta = \frac{60 \times 220}{60 \times 220 + 2020} = \text{about } 86{\cdot}5\,\%$$

$$C = 80$$

$$\eta = \frac{80 \times 220}{80 \times 220 + 2370} = \text{about } 89\,\%$$

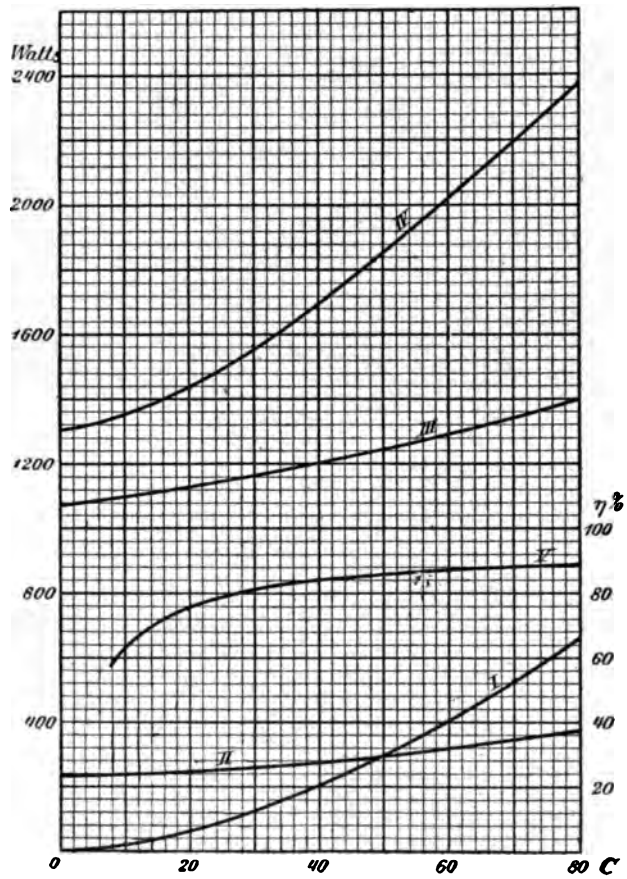



FIG. 207.

Curve V. in Fig. 207 represents the efficiency for the various loads.

# Experiment No. XXI

*Determination of the Efficiency of a Series Machine by the Indirect Method.*

DIAGRAM OF CONNECTIONS.

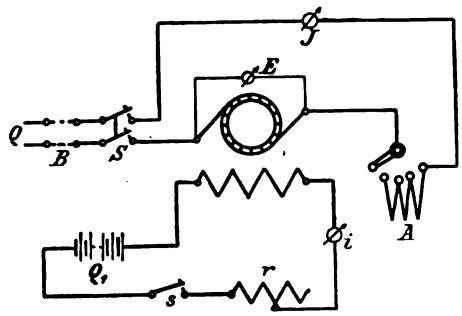



FIG. 208.

*Instruments and Apparatus required.*

J = Ammeter for about 10–20 per cent. of machine current.
$i$ = Ammeter for exciting circuit (about $1\frac{1}{2}$ times normal machine current).
A = Starter and regulator.
$r$ = Regulating resistance in exciting circuit.
$Q_1$ = Battery or dynamo for excitation. The exciting voltage must be about 10–20 per cent. of the machine voltage (according to size), and should be variable. In the case of a variable voltage of the battery or exciter, $r$ is not required.
S = Double-pole switch.
$s$ = Single-pole switch.
B = Fuse.
One tachometer.

*Experiment.*—The method of determining the efficiency of a series machine is the same as that for a shunt machine. There is, however, in the experiment just the difference that it is not possible to run a series motor light. Thus the machine must be separately excited to determine the no-load losses.

Both the armature and field resistances must be measured in the usual manner.

The amount of the no-load losses depends, as we know, upon the

excitation and speed. In the case of a series dynamo the speed is constant, but the excitation varies with the load. In the case of a series motor, however, both the excitation and the speed vary with the load. To determine the efficiency for all loads it would therefore be insufficient to measure the no-load losses only at a certain speed and excitation. We must obtain the losses for all loads at the speeds and excitations which correspond to these loads.

In the following we shall only discuss the determination of efficiency for normal load.

### (*a*) Determination of Efficiency for Normal Load.

The machine must first be run for several hours with normal load and normal speed. Then measure the armature and field resistances, after which connect up the machine as in Fig. 208. The connections should be prepared so that the change requires as little time as possible, in order that the same temperature condition of the machine can be obtained. Close the switch *s* in the exciting circuit, and adjust the exciting current to the normal machine current. With all the resistance of A in circuit, close S and adjust the speed to normal by regulating A or by varying the exciting voltage. After a few minutes, when a stationary state is reached, the terminal voltage and armature current must be read and recorded. The product of these diminished by the $C^2R$ losses in the armature represents the no-load loss; from the total losses the efficiency is then calculated.

### Example XXIa.

*Determination of Efficiency of a Series Motor by the Indirect Method.*

Machine, No. 457M. Type and maker, 8/5DE, Joseph Adamson & Co., Hyde.

Voltage, 220; current, 17 amps.; output, 14 B.H.P.; revolutions per minute, 500.

Instruments used—Voltmeter, No. 1236; Ammeters, Nos. 1236 and 1277.

#### Table of Results.

(1) Armature resistance
Measured by the indirect method.
Resistance = $1{\cdot}3\omega$ hot ($C_a = 17$ amps.).
Resistance = $1{\cdot}425\omega$ hot ($C_a = 1{\cdot}5$ amps.).

(2) Field resistance
Measured by the indirect method.
Resistance = $0{\cdot}85\omega$ hot.
Four coils in series.

(3) No-load losses
Armature voltage, 180.
Armature current, 1·5 amps.
Speed, 505 revolutions per minute.

*Determination of Losses.*

(1) Ohmic loss in armature

$$P_0 = C^2 r_a = 17^2 \times 1{\cdot}3 = 375{\cdot}7 \text{ watts}$$

(2) Ohmic loss in field coils

$$P_m = C^2 r_m = 17^2 \times 0{\cdot}85 = 245{\cdot}65 \text{ watts}$$

(3) No-load losses.
The energy consumed at $n = 505$ revolutions per minute was

$$180 \times 1{\cdot}5 = 270 \text{ watts}$$

From these, the $c_0^2 r_a$ losses in the armature must be deducted ($c_0$ = no-load current, $r_a$ = armature resistance with no-load current)

$$c_0^2 r_a = 1{\cdot}5^2 \times 1{\cdot}425 = 3{\cdot}2 \text{ watts}$$

Thus

$$\text{No-load losses} = 270 - 3{\cdot}2 = 266{\cdot}8 \text{ watts}$$

The total losses are

| | | |
|---|---|---|
| Armature loss | = | 375·7 watts |
| Field loss | = | 245·6 ,, |
| No-load losses | = | 266·8 ,, |
| Total ... | | 888·0 watts (approx.) |

The efficiency

$$\eta = \frac{EC - \text{total losses}}{EC}$$

$$E = 220 \qquad C = 17$$

Thus—

$$\eta = \frac{220 \,.\, 17 - 888}{220 \,.\, 17} = 76\tfrac{1}{2}\% \text{ (approx.)}$$

(*b*) Determination of Efficiency of a Series Machine for all Loads.

In the case of a generator proceed as follows: After the machine has been running for several hours with full load and normal speed, and its armature and field resistance has been

measured, connect it up as shown in Fig. 208. Close switch $s$ and adjust the exciting current by means of $r$ or by adjusting the voltage of $Q_1$, to about $1\frac{1}{2}$ of the normal machine current. The main circuit can then be closed and the motor started. Short-circuit A, and the speed will, with normal voltage E, probably be below the normal. In this case E must be increased until the machine assumes its normal speed. Then read and record the terminal voltage and the armature current. Next reduce the current in the exciting circuit to say $\frac{3}{4}$ of the normal current, and reduce the speed to its normal value by means of A. Again read the voltage and current and repeat for smaller exciting currents. The smaller the latter, the smaller must the machine voltage also be, if the speed is to remain constant. This experiment can only be made up to a certain limit, as with very small exciting currents the readings become no longer reliable. If the results obtained, *i.e.* the no-load watts, are plotted as a function of the exciting current, the lower part of the curve can either be estimated or can be found by calculation.

Let E be the voltage, $a$ a constant depending upon the friction loss and $b$ a constant depending upon the armature dimensions, and P the energy consumed by the armature; then—

$$P = a + bE^2$$

If several points of the curve are known, the constants $a$ and $b$ can be calculated, and thus the remainder of the curve estimated.

If the ohmic losses be deducted from the no-load losses, the curve obtained represents the mechanical and magnetic losses as a function of the load current. From this curve and the known resistances the efficiency is found in the usual way.

With series *motors* we must consider that with constant terminal voltage both the excitation and the speed vary with the load. To determine the no-load losses for all loads, the relation between speed and load must be known. The external characteristic of the motor must hence first be found (see Experiment XVI.). This experiment should, whenever possible, be made with the machine hot; for, with the machine in the cold state, the total voltage drop is smaller, and consequently the speed of the machine larger than in the hot state. If necessary, however, the speed curve can be determined with the machine cold, and can be calculated for the hot state. Let $n$ be the speed of the machine when cold, $n'$ when hot, $r_t$ the total resistance (armature + field) in cold state, $r_{t_1}$ in the hot state; then—

$$n' = n \cdot \frac{E - Cr_{t_1}}{E - Cr_t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (50)$$

where E stands for the terminal voltage.

When the speed curve has thus been found, and the resistances measured, the machine must be connected up as shown in Fig. 208, and the no-load losses obtained for a number of different exciting currents *and* the corresponding speeds. For instance, assuming the motor under test has the characteristic shown in Fig. 209, the exciting current would first be adjusted to C = 12 amps. The motor would then be started and by means of the main regulating resistance the speed brought to 500 revolutions per minute. After measuring the no-load watts, the measurement would be made for C = 10, $n$ = 550; C = 8, $n$ = 630; C = 6, $n$ = 800; C = 4, $n$ = 1050; C = 2, $n$ = 1500. The no-load watts measured must be

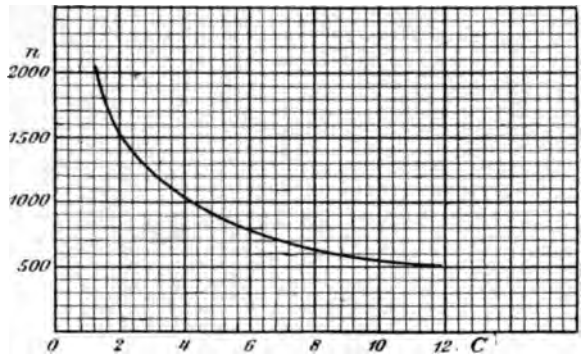



FIG. 209.

plotted against the current (main and exciting current being here the same); the efficiency is then found as in the previous experiments.

In the following are given two examples for the determination of efficiency of series machines at all loads, for a generator and a motor respectively.

## EXAMPLE XXIB.

*Determination of Efficiency of a Series Motor (for all Loads) by the Indirect Method.*

Machine, No. 457M. Type and maker, 8/5DE, Joseph Adamson & Co., Hyde.

Voltage, 220; current, 17 amps.; output, 4 B.H.P.; revolutions per minute, 500.

Instruments used—Weston set.

This motor was built for crane-work, *i.e.* for intermittent load. The maximum overheating specified was 50° C. This overheating was reached after

| | | | | |
|---|---|---|---|---|
| 6 | hours' | working with | 8·0 | amps. |
| 3 | ,, | ,, | 11·5 | ,, |
| 1 | ,, | ,, | 18·5 | ,, |

The machine was first loaded for 1 hour with 18·5 amps., and the resistances then measured. The results were as follows:—

| | | | |
|---|---|---|---|
| 2 amps. | Armature | = 1·46$\omega$ | Field 0·85$\omega$ |
| 5 ,, | ,, | = 1·4$\omega$ | ,, 0·85$\omega$ |
| 8 ,, | ,, | = 1·35$\omega$ | ,, 0·855$\omega$ |
| 13 ,, | ,, | = 1·32$\omega$ | ,, 0·845$\omega$ |
| 16 ,, | ,, | = 1·31$\omega$ | ,, 0·85$\omega$ |

Fig. 210 shows the armature, field, and total resistances as functions of the current.

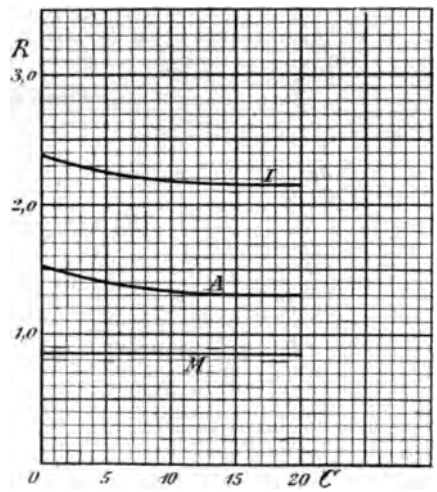



FIG. 210.

The machine was then loaded again for 1 hour with 18·5 amps., and the characteristic determined (see Fig. 211).

The machine was next run for some time with normal speed, so that the bearings could reach their final temperature. The bearing temperature and the energy consumed by the armature were

recorded (the speed being constant). The results of this experiment are given in the following table :—

TABLE OF RESULTS.

| Time (a.m.). | Exciting current, amps. | Armature current, amps. | Armature voltage. | Watts consumed. | $n$ | Bearing temperature. |
|---|---|---|---|---|---|---|
| 10.0 | 16·0 | 1·88 | 220 | 410 | 635 | 16° |
| 10.15 | ,, | 1·86 | ,, | 405 | ,, | 19° |
| 10.30 | ,, | 1·82 | ,, | 395 | ,, | 22° |
| 10.45 | ,, | 1·78 | ,, | 387 | ,, | 24° |
| 11.0 | ,, | 1·72 | ,, | 375 | ,, | 27° |
| 11.15 | ,, | 1·72 | ,, | 375 | ,, | 29° |
| 11.30 | ,, | 1·70 | ,, | 370 | ,, | 31° |
| 11.45 | ,, | 1·69 | ,, | 369 | ,, | 32·7° |
| 12.0 | ,, | 1·69 | ,, | 369 | ,, | — |
| 12.15 | ,, | 1·69 | ,, | 369 | ,, | 35° |

Air temperature, 16° C.

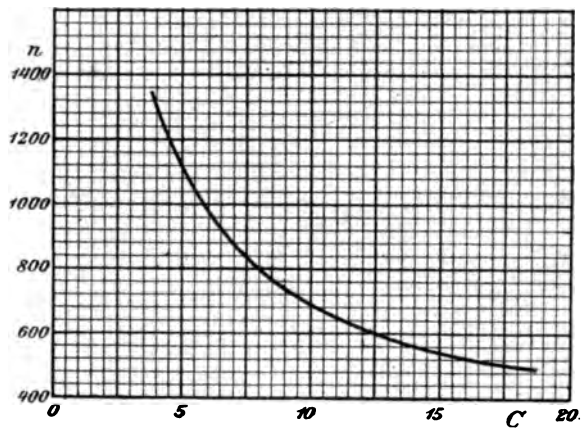



FIG. 211.

Curve I. in Fig. 212 shows the bearing temperature, Curve II. the energy consumed by the armature as a function of time. From these curves it is obvious that the bearing temperature increases with the time of run, and finally, after a certain time becomes constant. On the other hand, the energy consumed by the armature decreases with

the time of working. When the temperature of the bearings becomes a maximum, the energy consumed by the armature is a minimum. Since both the excitation and the speed have been kept constant during the experiment, the magnetic losses must have remained

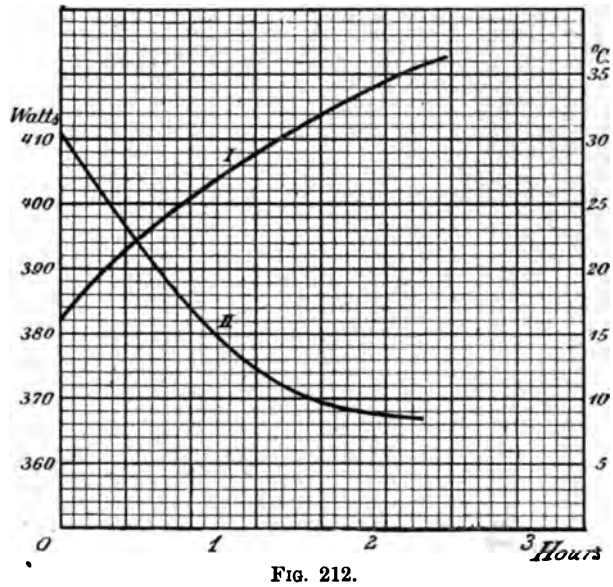



FIG. 212.

also constant. Hence the decrease in the no-load losses can only be accounted for by a decrease in the mechanical (friction) losses (compare also p. 208).

Lastly, the no-load losses were determined—the corresponding points of speed and excitation having been taken from the characteristic (Fig. 211).

The results were:

| Exciting current, C | Armature current, $C_a$ | Armature voltage, E | $n$ | $EC_a - C_a^2 r_a$ |
|---|---|---|---|---|
| 5·94 | 1·77 | 218·8 | 1000 | 384 |
| 8·0 | 1·62 | 206·4 | 800 | 330 |
| 9·8 | 1·61 | 202·0 | 700 | 320 |
| 12·5 | 1·5 | 191·0 | 600 | 284 |
| 17·0 | 1·5 | 179·4 | 505 | 265 |

In Fig. 213 Curve I. represents the no-load losses as a function of the exciting current, that is to say, of the load.

From this curve we see that the no-load losses of a series motor decrease with increasing load, whereas with a shunt motor they are nearly constant at all loads. With the latter both excitation and

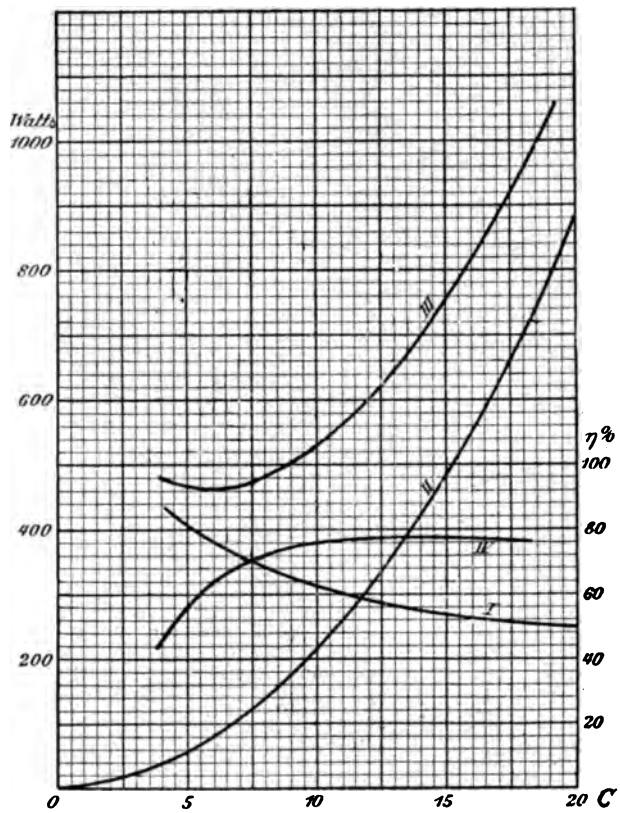



FIG. 213.

speed are nearly independent of the load, but with the series motor the excitation increases with the load, while, simultaneously, the speed falls. Owing to the falling speed the mechanical losses decrease. The magnetic losses are increased by the increasing excitation, and diminished by the decreasing speed. The result is that within certain limits the magnetic losses are nearly constant,

and that consequently the sum of the magnetic and the mechanical losses, *i.e.* the no-load losses, decrease with increasing load.

In the following table the separate losses and their sum are given for various loads :—

| Current. | No-load losses, watts. | Ohmic losses, watts. | Total losses, watts. |
|---|---|---|---|
| 4·0 | 445 | 36 | 481 |
| 5·94 | 384 | 79 | 463 |
| 8·0 | 340 | 141 | 481 |
| 9·8 | 320 | 210 | 530 |
| 12·5 | 284 | 340 | 624 |
| 17·0 | 265 | 623 | 888 |
| 19·0 | 250 | 778 | 1028 |

From this table the efficiency is found as follows :—

| Current. | Total losses, watts. | Watts delivered. | Watts consumed. | Efficiency, percentage. |
|---|---|---|---|---|
| 4·0 | 481 | 399 | 880 | 45·2 |
| 5·94 | 463 | 843 | 1306 | 64·6 |
| 8·0 | 478 | 1289 | 1767 | 73·5 |
| 9·8 | 530 | 1626 | 2156 | 75·5 |
| 12·5 | 624 | 2126 | 2750 | 77·0 |
| 17·0 | 888 | 2852 | 3740 | 76·5 |
| 19·0 | 1028 | 3152 | 4180 | 75·5 |

In Fig. 213 Curve II. represents the ohmic losses, Curve III. the total losses, and Curve IV. the efficiency as a function of the load.

## Experiment No. XXII

*Determination of Efficiency of a Compound Dynamo by the Indirect Method.*

DIAGRAM OF CONNECTIONS.

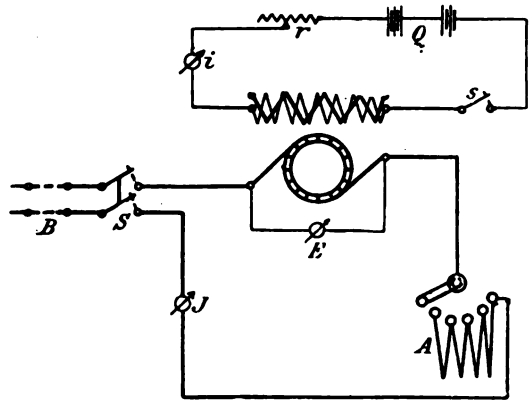



FIG. 214.

*Instruments and Apparatus required.*

J = Ammeter for about 1½ times normal current.
E = Voltmeter.
*i* = Shunt ammeter.
A = Starter and regulator.
*r* = Shunt resistance.
S = Main switch.
B = Fuse.
*s* = Field switch.
Q = Source of E.M.F. for excitation of voltage about 25 per cent. above voltage of the machine.

*Experiment.*—Determine first the characteristic of the dynamo (preceded by a several hours' run with full load and normal speed). The resistances of armature and field windings must also be measured.

In determining the no-load losses, we must consider that the various loads of a compound dynamo have corresponding various excitations, since the total ampere-turns increase with the load. We could evidently replace the total ampere-turns due to the compound winding by a corresponding number of shunt ampere-turns. To find

the shunt excitation corresponding to the compound excitation proceed as follows:—

Connect the machine up as shown in Fig. 214, and separately excite the field with a voltage higher than the normal machine voltage. Use A as loading resistance. Next bring the machine to its normal voltage, load it gradually, and adjust the voltage of the machine by means of the shunt regulator so that it corresponds to the characteristic found previously. Read the armature currents and the corresponding shunt currents. Thus a curve is obtained, showing the relation between the load and the total excitation (replaced by the shunt excitation). This curve must be used for the determination of the no-load losses as shown in Experiment No. XX. The losses must be measured for constant speed and variable excitations (taken from this curve). Since for a definite load there is always a definite excitation, the no-load watts obtained from this experiment are expressed as a function of the load. From these losses and the resistances measured, the efficiency may be found.

## 7. Additional Losses

The essential feature of the indirect method is the measurement of the losses due to hysteresis, eddy currents, and mechanical friction. These losses are measured when the machine is running light. It is hence assumed that these losses are constant when the machine is loaded. We have now to examine whether this is really so.

With regard to the bearing friction, we already know that the friction loss is independent of the load unless the maximum specific bearing pressure exceeds about 550 lbs. per square inch. As this limit is hardly ever reached with good machines, the above assumption is correct.

It is evident the same refers to the brush and air frictions.

The hysteresis and eddy-current losses taking place in the armature core and the end plates depend upon the periodicity, the volume, the quality of the material employed, and the 1·6th and 2nd powers of the maximum induction respectively. The former do not depend upon the load (the speed being always considered in measuring these losses); but the maximum induction varies with the load. We have learnt that armature reaction causes a considerable distortion of the magnetic field (see Fig. 110), and since the magnetic losses depend upon the 1·6th and 2nd power of the **maximum** induction respectively, the increase in loss due to the increase of induction will at some points be larger than the decrease in loss due to the weakened field at other points. We gather that the magnetic losses rise with increasing load.

The same refers to the losses occurring in the pole-shoes.

With regard to the losses in the armature conductors, we have seen that these are larger, the more irregular the field between the armature and the pole-shoes is. Hence these losses, too, increase with the load.

The eddy currents in the commutator bars are zero for no-load and increase with the square of the current flowing through the brushes, *i.e.* with the square of the load.

Finally, with ring armatures a loss is involved by the field produced by the conductors in the interior of the ring. This loss depends only upon the load.

Thus all the magnetic losses increase with increasing load, and consequently the assumption made before is incorrect. The difference between the magnetic losses at full and at no-load is called "additional iron loss," or shortly, "additional loss." The determination of the efficiency by the indirect method is therefore not quite correct unless the additional losses are considered.

The measurement of the additional losses is by no means simple. For instance, one method would be to determine the efficiency first by the indirect method and afterwards by the brake method. This, however, would only give reliable results if both experiments could be performed with the greatest accuracy, otherwise errors in either would make the whole experiment useless.

Thus, as a rule, the additional losses are either not considered at all, or a certain percentage of the total losses are allowed for them.

From a great number of experiments the author has found these losses to amount with machines of medium size to about 1–2 per cent. of the total output.

Notwithstanding this disadvantage the indirect method is owing to its simplicity employed in the majority of cases, especially for determination of efficiency of machines which are already installed.

## 8. The Auxiliary Motor Method

Though the determination of the magnetic and mechanical losses by the no-load method has certainly the advantage of being very simple and accurate, it cannot be employed in all cases, as for instance when a voltage equal to that of the machine to be tested is not available.

In such cases the no-load losses may be determined by the auxiliary motor method. The machine to be tested is coupled directly to (or driven by means of a belt by) an auxiliary motor. The former is fully excited, and the energy consumed by the motor is

measured. This energy represents the sum of the no-load losses of both machines. The auxiliary motor is then run alone, and the energy consumed is again measured; speed and excitation of the auxiliary motor must, of course, be the same as in the first case. The difference between the two energies measured is equal to the no-load losses of the machine under test.

In this way the no-load losses of a machine can be determined for any required excitation and speed.

This method has the advantage that it can be employed more universally than the no-load method, without any alteration in the method for series and shunt machines. On the other hand, the auxiliary motor must be at least as large as the machine under test, so that even with the maximum load possible, namely, the sum of the no-load losses or power of both machines, the auxiliary motor shall not be loaded considerably. Only in this case can the additional losses be neglected, and the no-load loss assumed equal to the difference of the two energies measured. Thus for this experiment a fairly large motor is necessary. If this motor can be coupled directly with the machine to be tested, the measurement can be made with a relatively great accuracy. If, however, a belt be used, the loss due to slip ought to be taken into account. The result is then no more accurate than in the former case.

Which of the two methods is to be chosen, viz. the auxiliary or the no-load method, depends upon the special cases referred to above.

## Experiment No. XXIII

*Determination of Efficiency by the Auxiliary Motor Method.*

DIAGRAM OF CONNECTIONS.

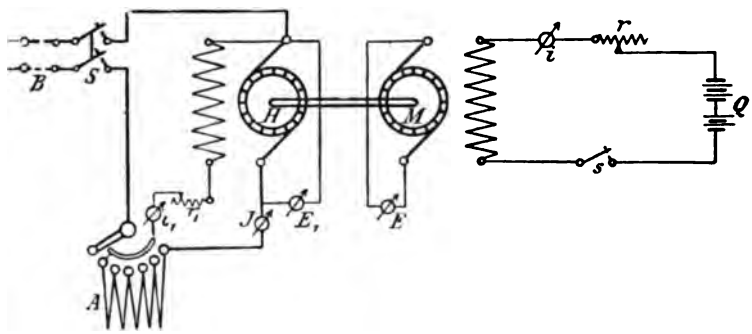



FIG. 215.

*Instruments and Apparatus required.*

(*a*) For the auxiliary motor, H—

J = Ammeter for about 50 per cent. of normal current.
$E_1$ = Voltmeter (normal voltage).
A = Starter and regulator.
$i_1$ = Shunt ammeter.
$r_1$ = Shunt regulator.
S = Main switch.
B = Fuse.

(*b*) For the machine to be tested, M—

E = Voltmeter.
$i$ = Shunt ammeter.
$r$ = Shunt regulator.
Q = Source of current, the voltage of which should be about 10–20 per cent. above the machine voltage.
$s$ = Field switch.
One tachometer.

*Experiment.*—Start the auxiliary motor H by closing S, make $r_1 = 0$, and gradually short-circuit A. Then, by means of the shunt regulator $r_1$, adjust the speed to that for which the no-load losses are required. Next close $s$ and adjust also the shunt current to that for which the no-load losses are to be found. If the speed has in the mean time dropped, increase again by means of the shunt regulator of the auxiliary motor.

Read the armature voltage and the current consumed by the auxiliary motor. The product of these, diminished by the $C^2R$ loss in the auxiliary motor is equal to the no-load losses of both machines (the auxiliary motor and the machine to be tested). If the no-load losses of the latter machine are to be determined for various excitations, the shunt current must, after the first reading, be correspondingly adjusted by means of $r$. If the speed should thereby alter, it must be again adjusted by varying the terminal voltage of the auxiliary motor, *i.e.* by adjusting the regulator A. It is best to start with a maximum excitation of M; if its excitation is weakened, the speed of the motor will in all probability increase, and can be reduced to normal by inserting some resistance A in the main circuit. Care must be taken not to vary the shunt current of the auxiliary motor once the experiment has been started; otherwise the magnetic losses of the auxiliary motor would be altered, and would produce erroneous results.

When the sum of the no-load losses of both machines have been determined for a number of different excitations of M—with constant speed and excitation of H—the two machines must be uncoupled, and the auxiliary motor run alone. The excitation of H must be

exactly the same as before, and should its speed be now larger, it must be reduced by means of the main regulator A. Armature voltage and current must be read and registered.

Determine the total armature resistance of the auxiliary motor in order to deduce its ohmic loss.

The experiment is the same for shunt machines and series generators; with series motors, however, the no-load losses must be

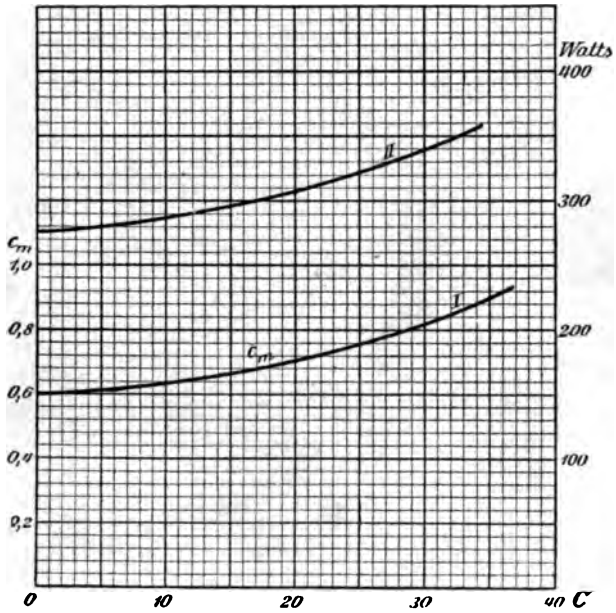



FIG. 216.

determined for various excitations and speeds. For series motors proceed as follows:—

Couple the machines and measure the no-load losses for various excitations of M and various speeds; as it will also be necessary to vary the excitation of H, this should always be read. Then uncouple the machines and measure the no-load watts of the auxiliary motor alone for the different speeds and corresponding excitations with which the auxiliary motor worked.

The difference of the two series of readings of the no-load watts will be equal to the no-load watts of M at the various speeds and excitations. The efficiency is then found in the usual way.

In the following is given an example for the determination of the no-load losses of a shunt dynamo by the auxiliary motor method.

## EXAMPLE No. XXIII.

*Determination of No-load Losses of a Shunt Dynamo by the Auxiliary Motor Method.*

The machine tested was a 1·5 K.W. Schuckert dynamo for $n = 1200$ revolutions per minute. The machine was first run with full load for 3½ hours. Then the shunt current was determined as a function of the load with normal speed and constant voltage—70 volts. The machine was separately excited. In Fig. 216, Curve I. shows this relation.

An auxiliary motor was next coupled to the machine, and both run for another 3½ hours. The no-load losses were then measured. The results of this experiment are given in the following table:—

| MACHINE TO BE TESTED. | | AUXILIARY MOTOR. | | |
|---|---|---|---|---|
| Shunt current. | Speed. | Terminal voltage. | Armature current. | Exciting current. |
| | | Both machines coupled. | | |
| 0·60 | 1200 | 218·0 | 3·25 | 0·7 |
| 0·64 | ,, | 218·5 | 3·3 | ,, |
| 0·70 | ,, | 220·0 | 3·35 | ,, |
| 0·82 | ,, | 220·5 | 3·5 | ,, |
| | | Motor alone. | | |
| — | ,, | 218·0 | 1·95 | ,, |

The armature resistance of the auxiliary motor was

at 2 amps. ... $0{\cdot}5\omega$
at 3 ,, ... $0{\cdot}48\omega$

From this and the above table the following table was calculated:—

| Exciting current of machine tested. | Watt-consumption of motor (both machines coupled). $EC_a - C_a^2 r_a$ | Watt-consumption of auxiliary motor running alone. | No-load watts of machine to be tested. |
|---|---|---|---|
| 0·60 | 703·7 | 426 | 277·7 |
| 0·64 | 716·0 | ,, | 290·0 |
| 0·70 | 732·0 | ,, | 306·0 |
| 0·82 | 766·0 | ,, | 340·0 |

Curve II. in Fig. 216 shows the no-load watts as a function of the load.

## 9. The Hopkinson (Differential) Method

With this method two machines of the same size, output, and voltage are electrically and mechanically coupled together so that one running as a motor drives the other as a generator. The energy required to cover the total losses of the two machines is supplied either as mechanical or electrical energy and its amount measured. With the assumption that the losses are equally divided in both machines, *i.e.* that the efficiencies of the two machines are equal, the efficiency of each machine can be found from the total efficiency of the set.

The energy lost in the two machines can be supplied in three different ways, viz.—

(1) The coupled set can be driven by an auxiliary motor; the mechanical energy supplied by the latter can be measured either by a transmission dynamometer, or by braking the auxiliary motor.

(2) The coupled machines are connected in parallel and derive current from a dynamo. The latter must obviously be of the same voltage as the machines under test. The energy supplied by this auxiliary machine is equal to the losses of the set.

(3) The coupled machines are connected in series and derive current from a dynamo, the voltage of which must be variable and smaller than that of the machines to be tested. The energy supplied by this dynamo is again equal to the losses taking place in the set.

All these methods have, however, one great disadvantage, which makes them unfit for very accurate measurements, namely, the assumption made with regard to the efficiencies of the two machines being equal is incorrect, as the two machines must necessarily work with different excitations. On the other hand, these methods have the great advantage of being very simple and economical. For example, if a 100 H.P. motor is braked for 10 hours, the cost of energy would amount to about £10. By the Hopkinson test only a small amount of energy is lost, simply the losses of the respective machines.

The latter two methods mentioned above will be discussed separately.

### (*a*) Hopkinson Test with Two Parallel Connected Machines.

The connections of the machines are shown in Fig. 217. The source of current may either be a dynamo or preferably a battery of accumulators.

By means of the starter A the two machines are simultaneously

started as motors, both shunt regulators being still short-circuited. When the machines reach their normal speed, resistance is inserted in the shunt circuit of one machine, until the other machine working as a dynamo produces a current of the desired strength. It is evident that since the voltages of the machines are equal, the current $C_m$ consumed by the motor must be larger than the current $C_d$ delivered by the dynamo; the difference $C_m - C_d$ must be supplied by the accumulators (or auxiliary dynamo). The efficiency of the combined set, $\eta_c$, will then be—

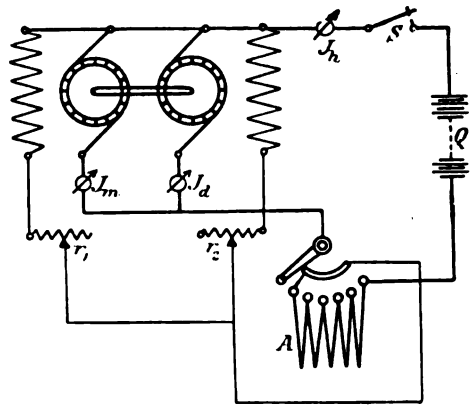



FIG. 217.

$$\eta_c = \frac{EC_d}{EC_m}$$

and since—

$$C_m = C_d + C_a$$

where $C_a$ stands for the current supplied by the accumulators—

$$\eta_c = \frac{EC_d}{E(C_d + C_a)} = \frac{C_d}{C_d + C_a} \quad . \quad . \quad . \quad . \quad . \quad . \quad (51)$$

Assuming now the efficiencies of the two machines to be equal, so that $\eta_m = \eta_d = \eta$

$$\eta_c = \eta^2$$

and

$$\eta = \sqrt{\frac{C_d}{C_d + C_a}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (52)$$

Hence two ammeters and two readings only are required. The third ammeter is used to check the readings of the two others.

If the efficiency of the two machines should be found for a certain current C, we must, as $C_d$ and $C_m$ can never be equal to each other, adjust $C_m$ and $C_d$ so that—

$$\frac{C_d + C_m}{2} = C$$

The efficiency may thus also be measured for any load other than the normal.

## (b) Hopkinson Test with Two Series Connected Machines.

Diagram of Connections.

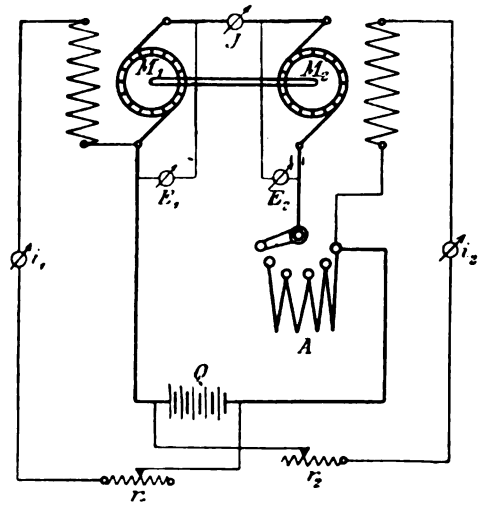



Fig. 218.

*Instruments and Apparatus required.*

$r_1$, $r_2$ = Shunt regulators.
J = Ammeter for maximum machine current.
$i_1$, $i_2$ = Shunt ammeters.
$E_1$, $E_2$, = Voltmeters.
A = Starter.
Q = Source of E.M.F., either a dynamo or a battery of accumulators.
$M_1$ and $M_2$ are the two machines to be tested.

The machines are excited either from the auxiliary machine or from the accumulators Q (provided the exciting voltage is sufficient). The motors are first started by means of the starter A. Next the current flowing through $M_1$ and $M_2$ is varied to the value required by varying the voltage of Q and the exciting current in one of the two motors. One of the machines, say $M_1$, works as a motor with a voltage $E_1$, the other works as a generator with a voltage $E_2$ which is smaller than $E_1$. The difference between these voltages is supplied by the accumulators. If the voltage on the latter is $E_3$, then—

$$E_3 = E_1 - E_2$$

so that $E_1$ and $E_2$ can be checked by $E_3$.

If we call the combined efficiency of the set $\eta_c$, that of $M_1 - \eta_m$, and that of $M_2 - \eta_d$, and assume that

$$\eta_d = \eta_m = \eta$$

then—

$$\eta_c = \frac{E_2C}{E_1C}$$

and—

$$\eta = \sqrt{\frac{E_2}{E_1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (53)$$

## 10. The Direct Electric Method

As has been before mentioned, this method can be employed with a special type of machine only, viz. with rotating continuous current transformers, *i.e.* machines which transform continuous current of one voltage to another. Such machines have generally but one field and armature core, with two distinct armature windings and two commutators; or two armatures with two commutators fixed on one shaft. In a few cases they consist of two separate machines coupled up together.

As with these machines both the energies supplied and consumed are electric, the measurement of the efficiency is very simple. The voltage and current consumed and delivered need only be measured. Then

$$\eta = \frac{\text{voltage} \times \text{current (supplied)}}{\text{voltage} \times \text{current (consumed)}}$$

In preparing for the actual measurement the converter is started and run for several hours with full load and normal speed. The diagram of connections is given in Fig. 219. The energies supplied and consumed must be measured at various loads of the machine. With the dynamo circuit open measure the no-load current; then close S and gradually load the dynamo. Take readings for about $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{4}{4}$, and $\frac{5}{4}$ of normal load. It is not essential to measure the speed, if the primary voltage is kept constant. For measuring the currents and voltages the same types of instruments should be used, so that their accuracies are about equal.

## Experiment No. XXIV

*Measurement of Efficiency of a Continuous Current Rotary Transformer (Direct Electric Method).*

DIAGRAM OF CONNECTIONS.

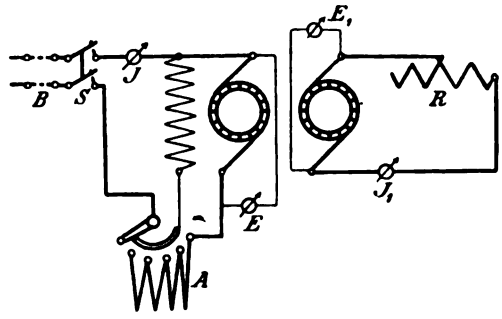



FIG. 219.

*Instruments and Apparatus required.*

J = Motor ammeter.
$J_1$ = Dynamo ammeter.
E = Motor voltmeter.
$E_1$ = Dynamo voltmeter.
A = Starter.
R = Loading resistance.
S = Main switch.
B = Fuse.

*Experiment.*—See above remarks.

### EXAMPLE XXIV.

*Determination of Efficiency of a Continuous Current Rotary Transformer (Direct Electric Method).*

Machine, No. 6616. Type and maker, Electric Construction Co. Number of poles, 2.

Voltage (primary), 220 ; current (primary), 38 amps.
Voltage (secondary), 20 ; current (secondary), 100 amps.
Output, 2 K.W. ; speed, 1350 revolutions per minute.

TABLE OF RESULTS.

| Motor voltage, $E_1$ | Motor current, $C_1$ | Motor watts, $E_1C_1$ | Dynamo voltage, $E_2$ | Dynamo current, $C_2$ | Dynamo watts, $E_2C_2$ | Efficiency in percentage. |
|---|---|---|---|---|---|---|
| 220 | 5·3 | 1166 | 18·8 | — | — | 0·0 |
| ,, | 6·7 | 1474 | 18·6 | 15 | 279 | 19·0 |
| ,, | 7·13 | 1569 | 18·4 | 25 | 460 | 29·2 |
| ,, | 7·97 | 1753 | 18·3 | 30 | 549 | 31·4 |
| ,, | 8·47 | 1863 | 18·25 | 35 | 639 | 34·2 |
| ,, | 9·00 | 1980 | 18·4 | 40 | 736 | 37·2 |
| ,, | 9·44 | 2077 | 18·0 | 45 | 810 | 39·0 |
| ,, | 9·88 | 2174 | 18·0 | 50 | 900 | 41·4 |
| ,, | 11·05 | 2431 | 18·0 | 60 | 1080 | 44·5 |
| ,, | 12·20 | 2684 | 17·9 | 70 | 1253 | 46·5 |
| ,, | 15·69 | 3452 | 17·9 | 100 | 1790 | 52·0 |

In Fig. 220 the efficiency is plotted as a function of the secondary current.

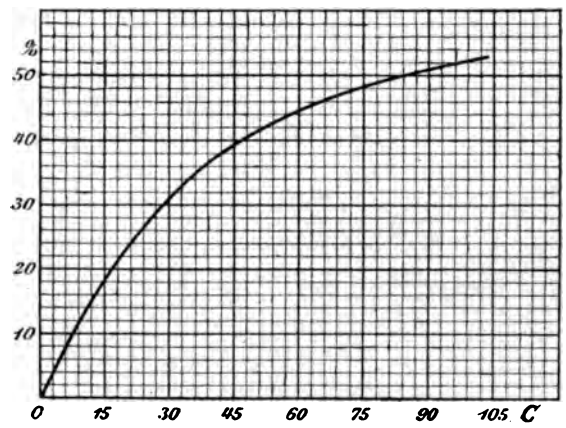



FIG. 220.

# CHAPTER X

# THE SEPARATION OF LOSSES

## Introduction

In the last chapter we dealt with the most important methods for the determination of efficiency. To the buyer of a machine the total efficiency is quite ample; but to the manufacturer and designer it is far more important to know the value of the individual losses than their sum. Knowledge of these will enable him to improve the machine until its output and efficiency become a maximum, with a minimum of cost for material and wages.

A complete separation of the individual losses is scarcely possible; but the principal losses can easily be separated from each other.

As stated in the last chapter, the losses arising in continuous current machines are as follows:—

(1) Ohmic loss in the armature winding.
(2) Loss due to contact resistance between the commutator and brushes.
(3) Ohmic loss in the field windings (including the losses arising in series or parallel resistances).
(4) Loss due to hysteresis in the armature core (including the teeth).
(5) Loss due to hysteresis in the pole-shoes.
(6) Loss due to eddy currents in the armature core.
(7) Loss due to eddy currents in the armature winding.
(8) Loss due to eddy currents in the pole-shoes.
(9) Loss due to eddy currents in the commutator bars.
(10) Loss due to bearing friction.
(11) Loss due to brush friction.
(12) Loss due to air friction (windage).
(13) Commutation losses.

The causes of all these losses have been discussed in the last chapter; it has been mentioned that the losses (1) to (9) and (13) vary with the load of the machine, while the remainder are independent of the load.

The losses (1) to (3) are easily measured by previously described methods. The individual resistances need only be measured, and from these the corresponding losses for any load are found by calculation.

The magnetic and mechanical losses can be measured in different ways, as indicated in the last chapter. To separate these two groups of losses we need only consider that the magnetic losses depend upon the inductions, *i.e.* the excitation of the machine, while the mechanical losses do not. If therefore we measure the no-load losses (*i.e.* the magnetic + mechanical losses), firstly with the machine excited, and secondly with the machine unexcited—the difference between the two energies measured will be equal to the magnetic losses at the particular excitation. In this manner the mechanical losses can be separated from the magnetic losses.

The latter consist of hysteresis and eddy-current losses. The separation of these is still possible, as they follow different laws. The hysteresis losses are directly proportional to the speed, while the eddy-current losses are proportional to the square of the speed. If the sum of both these losses is measured with different excitations and speeds they may, as will be shown later on, easily be separated from each other either graphically or by calculation.

A further separation of the losses is often not possible. In most cases we must therefore content ourselves with knowing the sum of all hysteresis losses and the sum of all eddy-current losses for various excitations.

The mechanical losses, which comprise the losses due to bearing, brush, and air frictions, can be separated in the following manner: The mechanical losses are first measured with the brushes on the commutator, and afterwards with the brushes up. The difference between the two losses is equal to the loss due to brush friction. The losses due to bearing and air frictions cannot very well be separated from each other.

The various methods employed for the separation of losses will now be dealt with separately.

## 1. Separation of Losses by Means of a (Calibrated) Auxiliary Motor

### Experiment No. XXV

The diagram of connections for this experiment is shown in Fig. 215. After a run of several hours the no-load losses should be m easured for various excitations and various speeds in the following w ay: First excite the machine M under test (see Fig. 215) with

about one-fifth of the normal exciting current by regulating either the voltage of Q or the shunt resistance $r$. Then vary the speed of the set by means of A and $r_1$ within wide limits, and read for the various speeds deflections on E, J, $i_1$, and $E_1$—the shunt current of M being kept constant. If H be a calibrated motor, the energy absorbed by M at the various speeds, *i.e.* the no-load losses of M, can be found directly from the calibration curve. Or they can be found by the method described on p. 237. From these results a curve can be plotted, showing the no-load losses of M as a function of its speed with constant excitation.

Repeat the experiment for excitation of M of say $\frac{1}{4}$ or $\frac{1}{3}$ normal; another curve can then be plotted; and so on perform experiments for $\frac{1}{2}$, $\frac{3}{4}$ normal, and $\frac{5}{4}$ of normal exciting current, and finally for no

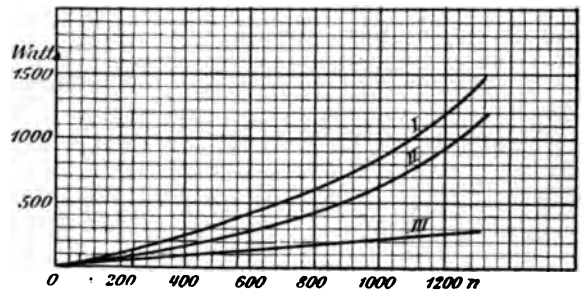



FIG. 221.

excitation. E will in the latter case show no voltage, or only a very small one.

Lastly, lift the brushes of M off the commutator and measure the no-load watts again for various speeds (machine being unexcited).

By means of the above results the losses can now be separated as follows:—

First plot the two curves for $c_m = 0$ (shunt circuit broken), with the brushes on and off the commutator respectively. In Fig. 221 these two curves are shown for a six-pole machine of about 60 K.W output. Curve I. represents the friction losses (with $c_m = 0$—the energy consumed by M is obviously spent in overcoming the frictional resistances only) with the carbon brushes on the commutator; Curve II. represents the friction losses with the carbon brushes taken off the commutator; the difference between I. and II.—Curve III.—represents the loss due to brush friction.

If we plot the curve representing the mechanical losses below the curve representing the no-load losses at full excitation as a

function of the speed, their difference will be equal to the magnetic losses for this (full) excitation. This is shown in Fig. 222. Curve II. represents the no-load losses at normal excitation of the machine referred to above; Curve I. represents the mechanical losses (see Curve I. in Fig. 221); the difference between I. and II.—*i.e.* Curve III.—represents, therefore, the magnetic losses as a function of the

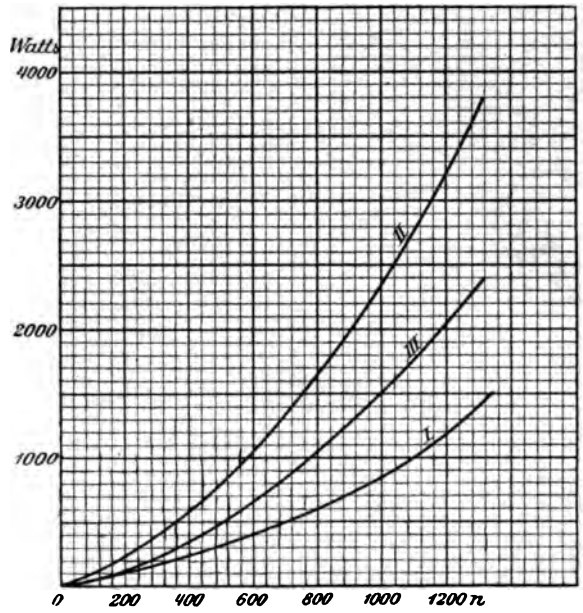



FIG. 222.

speed (excitation constant). By means of Curve III. the magnetic losses may be separated as follows :—

Let the magnetic losses due to an exciting current $c_m$ and a speed $n$ be P, and at a speed $n_1$ be $P_1$; then—

$$P = P_h + P_e$$
$$P_1 = P_{1h} + P_{1e}$$

where $P_h$ and $P_{1h}$ are the hysteresis losses at speeds $n$ and $n_1$, and $P_e$ and $P_{1e}$ the eddy-current losses at the speeds $n$ and $n_1$ respectively.

The hysteresis losses are directly proportional to the speed, and the eddy-current losses to the square of the speed; hence

$$P_h = K_h n$$
$$P_{1h} = K_h n_1$$

and

$$P_e = K_e n^2$$
$$P_{1e} = K_e n_1^2$$

thus

$$P = K_h n + K_e n^2 \quad . \quad . \quad . \quad . \quad . \quad (54)$$

and

$$P_1 = K_h n_1 + K_e n_1^2 \quad . \quad . \quad . \quad . \quad . \quad (55)$$

where $K_h$ and $K_e$ are constants, depending upon the dimensions and inductions of the parts in which the losses take place.

If from equation (54) we determine one of the constants $K_h$ or $K_e$, and insert in the equation (55), we shall obtain for the second constant an expression involving $n$, $n_1$, P and $P_1$ only. For instance, inserting equation (54)—

$$K_h = \frac{P - K_e n^2}{n}$$

in equation (55), we have—

$$P_1 = \frac{P - K_e n^2}{n} n_1 + K_e n_1^2$$

or

$$P_1 n = P n_1 - K_e n^2 n_1 + K_e n_1^2 n$$

thus

$$K_e = \frac{P n_1 - P_1 n}{n^2 n_1 - n_1^2 n}$$

or

$$K_e = \frac{P_1 n - P n_1}{n_1^2 n - n^2 n_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (56)$$

If from the curve showing the relation between the magnetic losses and speed we take for any two speeds $n$ and $n_1$ the corresponding values P and $P_1$, we can find $K_e$ by means of formula (56), *i.e.* the constant which multiplied by $n^2$ gives the eddy-current loss for the speed $n$. In this manner we can obtain a curve showing the eddy-current losses as a function of the speed. The difference between the total magnetic losses and the eddy-current losses is then equal to the hysteresis losses.

For instance, we have from Fig. 223 for—

$$n = 500 \quad \ldots \quad P = 500$$
$$n_1 = 1000 \quad \ldots \quad P_1 = 1500$$
$$K_e = \frac{1500 \,.\, 500 - 500 \,.\, 1000}{1000^2 \,.\, 500 - 500^2 \,.\, 100} = 0{\cdot}001$$

| | | | | | |
|---|---|---|---|---|---|
| Thus for | $n = 200$ | eddy-current | loss = | $200^2 \times 0{\cdot}001 =$ | 40 watts |
| „ | $n = 400$ | „ | „ = | $400^2 \times 0{\cdot}001 =$ | 160 „ |
| „ | $n = 600$ | „ | „ = | $600^2 \times 0{\cdot}001 =$ | 360 „ |
| „ | $n = 800$ | „ | „ = | $800^2 \times 0{\cdot}001 =$ | 640 „ |
| „ | $n = 1000$ | „ | „ = | $1000^2 \times 0{\cdot}001 =$ | 1000 „ |
| „ | $n = 1200$ | „ | „ = | $1200^2 \times 0{\cdot}001 =$ | 1440 „ |

Plotting these values (see Curve II., Fig. 223) and subtracting the ordinates from those of Curve I. (sum of magnetic losses), we get Curve III., which represents the hysteresis losses.

As mentioned above, Curve I. should be determined for various exciting currents. From a number of such curves two others can

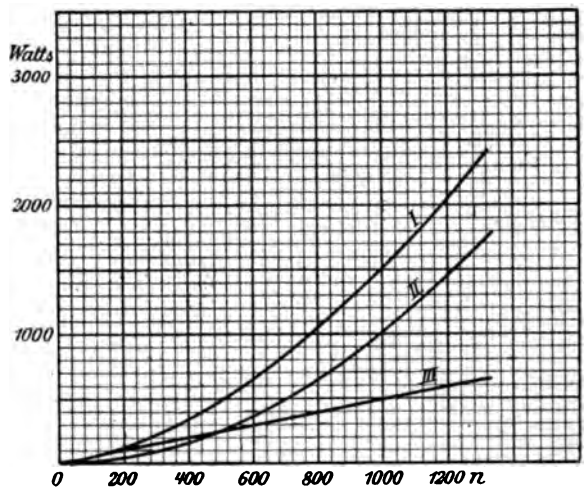



FIG. 223.

then be plotted representing the hysteresis and eddy-current losses as functions of the exciting current (with constant speed) respectively.

Such curves may, however, also be found by calculation, without measuring the magnetic losses at various excitations, if the magnetization curve of the machine be given; this latter shows, as we know, the relation between exciting current and E.M.F. (or induction). If, therefore, the hysteresis and eddy-current losses are known for a certain exciting current $c_m$, then at the same speed and exciting current $c_m$—

$$P_h : P_{1h} = B^{1{\cdot}6} : B_1^{1{\cdot}6}$$

and

$$P_e : P_{1e} = B^2 : B_1^2$$

The inductions B corresponding to an exciting current $c_m$, and $B_1$ corresponding to an exciting current $c_{m_1}$ (or their relative values) can be found from the magnetization curve.

## EXAMPLE XXV.

*Separation of Losses by Means of an Auxiliary Motor.*

The machine under test was a small Schuckert generator with an output of about 1·5 K.W. at 1200 revolutions per minute. The normal excitation for this machine varies from 0·6 to 0·8 amp. The 5 B.H.P. Thomson Houston already referred to was employed as auxiliary motor. The separation of losses is given below for one excitation only—for 0·6 amp.

Both machines were coupled up and had an initial run of three hours with 1200 revolutions per minute. The no-load losses of both machines were then measured; the auxiliary motor was excited with $c_m = 0·7$ (constant) and its speed regulated from $n = 1200$ to $n = 400$ by means of a main resistance. The excitation of the machine under test was kept constant throughout.

TABLE OF RESULTS.

| Armature current, $C_a$ | Armature voltage, E | Speed. | No-load losses, $C_aE - C_a^2r_a$ |
|---|---|---|---|
| 3·2 | 218·0 | 1200 | about 694 watts |
| 2·77 | 182·5 | 1000 | ,, 501 ,, |
| 2·46 | 146·0 | 800 | ,, 355 ,, |
| 2·13 | 109·5 | 600 | ,, 230 ,, |
| 1·8 | 73·0 | 400 | ,, 130 ,, |

The exciting circuit of the machine under test was next broken, while the shunt current of the auxiliary motor was still kept constant. The no-load losses found by the above experiment comprise the no-load losses of the auxiliary motor + magnetic and mechanical losses of the machine under test; but the no-load losses found with the field broken comprise the no-load losses of the auxiliary motor and the mechanical losses of the machine under test.

TABLE OF RESULTS.

| Armature current, $C_a$ | Armature voltage, E | Speed. | No-load losses, $C_aE - C_a^2r_a$ |
|---|---|---|---|
| 2·42 | 218·0 | 1200 | 526 watts |
| 2·05 | 182·0 | 1000 | 371 „ |
| 1·78 | 146·0 | 800 | 258 „ |
| 1·57 | 109·5 | 600 | 171 „ |
| 1·34 | 72·5 | 400 | 96 „ |

Lastly, the machines were uncoupled, and the auxiliary motor run alone with the same excitation as before and with variable speed. The results of this experiment are recorded in the following table:—

| Armature current, $C_a$ | Armature voltage, E | Speed. | No-load losses, $C_aE - C_a^2r_a$ |
|---|---|---|---|
| 1·94 | 218·0 | 1200 | 420 watts |
| 1·67 | 181·7 | 1000 | 300 „ |
| 1·48 | 146·0 | 800 | 215 „ |
| 1·30 | 109·0 | 600 | 140 „ |
| 1·12 | 72·5 | 400 | 80 „ |

The difference between the no-load losses of the first and the second table is equal to the magnetic losses (see Curve I., Fig. 224); the difference between the first and the third is equal to the total no-load losses of the machine under test (Curve II., Fig. 224).

Curve III., which is equal to the difference in ordinates between Curves I. and II., represents the mechanical losses as a function of speed at a constant excitation.

Curve I. is again plotted in Fig. 225 (as Curve III.). To separate the hysteresis and eddy-current losses we use formula (56).

From

$$P_1 = 60 \qquad n_1 = 600$$
$$P_2 = 170 \qquad n_2 = 1200$$

we get

$$K_e = \frac{170 \,.\, 600 - 60 \,.\, 1200}{1200^2 \,.\, 600 - 600^2 \,.\, 1200} = 0{\cdot}0000695$$

Hence the eddy-current loss is—

$$\text{at } n = 600 = K_e \,.\, 600^2 = 25 \text{ watts}$$
$$\text{at } n = 1200 = K_e \,.\, 1200^2 = 100 \text{ watts}$$

If we draw a straight line (I. in Fig. 225) through the two points

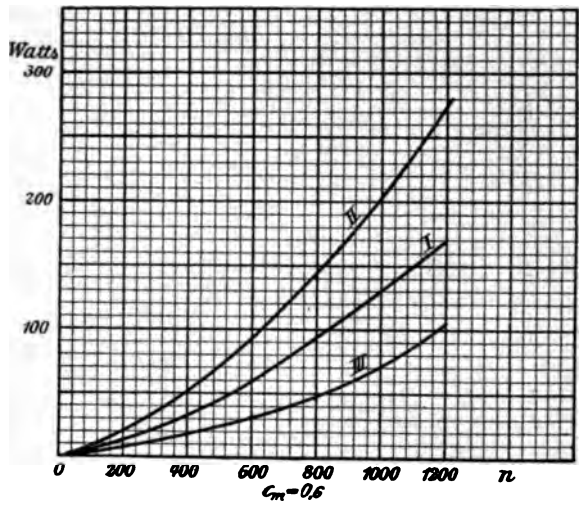



FIG. 224.

thus obtained, the hysteresis losses will be separated from the eddy-current losses.

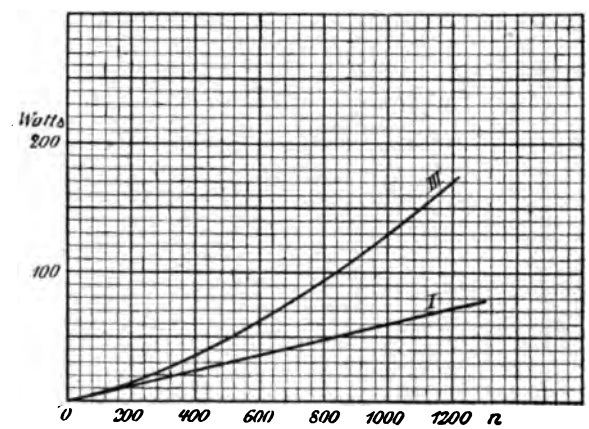



FIG. 225.

In the same way the magnetic losses may be determined for any other excitation, and then be separated as above.

## 2. Separation of Losses by Dettmar's Method *

### Experiment No. XXVI

If a machine is driven as a motor with constant speed but variable excitation—with variable terminal voltage—the energy consumed will be smaller the smaller the excitation, *i.e.* the smaller the terminal voltage. With decreasing excitation the losses due to hysteresis and eddy currents decrease, while the losses depending upon the speed only remain constant. For $E = 0$ the magnetic losses will be zero, and apart from a small ohmic loss in the armature, the energy consumed will cover the mechanical losses only.

In this way the mechanical losses can be determined for a constant speed. To find the relation between the mechanical losses and speed, the above experiment must be made for different speeds, and a group of curves obtained as shown in Fig. 226. It is of course impossible to determine the whole of the curve by experiment; in most cases two-thirds of it only can be determined. Each must then be produced by approximation so that it intersects the co-ordinate; this may also be done by calculation.

The equation of the curves referred to above is—

$$P = a + bE^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (57)$$

where P stands for the energy consumed by the motor;
$a$ „ „ friction loss;
E „ „ terminal voltage of the armature;
$b$ „ a constant depending upon the speed and armature dimensions.

Hence, if two points of the curve are given, viz. $P_1$, $E_1$ and $P_2$, $E_2$, the friction loss $a$ can be found for the respective speed; since—

$$P_1 = a + bE_1^2$$

and

$$P_2 = a + bE_2^2$$

we have

$$b = \frac{P_1 - a}{E_1^2}$$

and

$$a = \frac{P_2E_1^2 - P_1E_2^2}{E_1^2 - E_2^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (58)$$

In Fig. 226 the results of such an experiment are plotted for $n = 900$, 700, and 500; the full lines of the curves were found by experiment. The points of intersection of these curves with the

* See *Elektrotechnische Zeitschrift*, 1899, p. 203.

co-ordinate give the values of $a$ for the respective speed. For instance, for $n = 900$

$$P_1 = 500 \qquad E_1 = 80$$
$$P_2 = 610 \qquad E_2 = 120$$

$$a_{900} = \frac{610 \,.\, 80^2 - 500 \,.\, 120^2}{80^2 - 120^2} = 412$$

In the same way $a$ may be found for $n = 700$ and $n = 500$.

If several of these curves have been determined for say $n = \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, \frac{4}{4}$, and $\frac{5}{4}$ normal, another curve can be plotted showing the friction loss as a function of the speed. This curve will, as we know, bend upwards.

With the friction losses being determined for all speeds, the magnetic losses must next be separated into hysteresis and eddy-current losses. For this purpose the machine must be run with

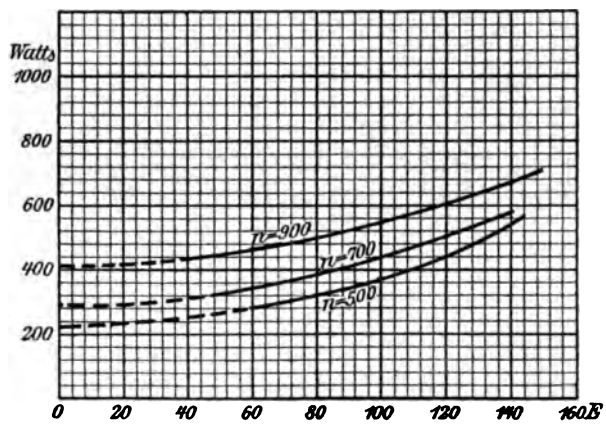



FIG. 226.

constant excitation and variable voltage—with variable speed—and the current consumed measured. If the latter is plotted as a function of the voltage, a straight line is usually obtained. This represents the current necessary to overcome the magnetic and mechanical losses. We have then to determine from the friction curve the currents corresponding to the friction losses at these voltages for a few speeds (or corresponding voltages). This current is obtained by dividing the friction loss in watts by the corresponding voltage at the particular speed for the given excitation.

An example will make this clearer. Fig. 227 represents the friction losses of a machine as a function of speed and voltage ($c_m = 0{\cdot}5$). In

Fig. 228 Curve I. represents the no-load current as a function of the

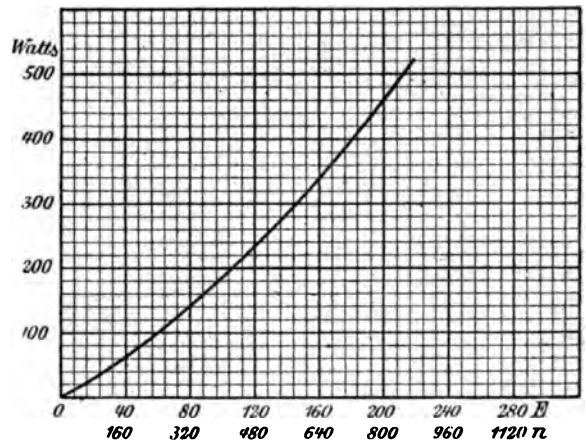



FIG. 227.

terminal voltage with the same excitation. At a voltage of 80 the

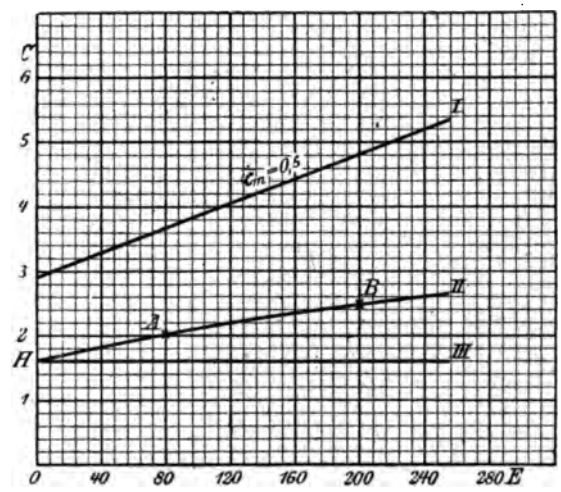



FIG. 228.

friction loss is equal to 140 watts, thus the current necessary to overcome the frictional resistance

$$C_1 = \frac{140}{80} = 1{\cdot}75 \text{ amps.}$$

Point A in Fig. 228 has as abscissa E = 80 and ordinate $C_1 = 1{\cdot}75$. In the same way, any number of points may be found, for instance for point B, E = 200, $a = 460$, and—

$$C_2 = \frac{460}{200} = 2{\cdot}3$$

If we connect the points thus determined by a curve (II.), it will represent the current necessary to overcome the magnetic resistances for the various voltages (or speeds).

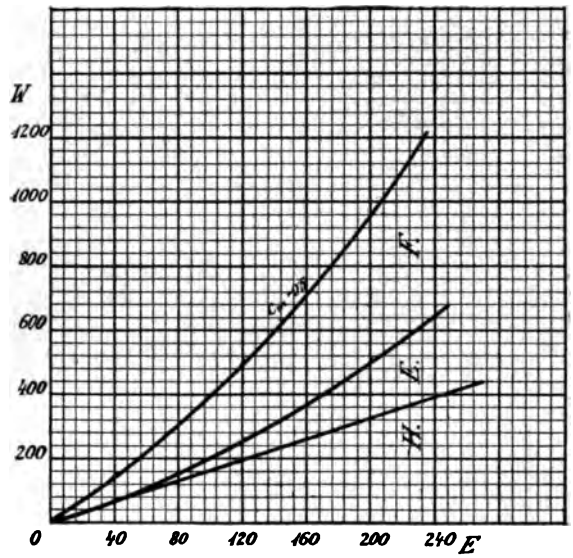



FIG. 229.

To separate the magnetic losses a straight line (III.) is drawn parallel to the abscissa through the point of intersection of Curve II. with the co-ordinate. OH represents the (constant) current corresponding to the hysteresis, and the ordinate differences between II. and III. represent the currents corresponding to the eddy-current loss which are proportional to the voltages (speeds). From the curves in Fig. 228 other curves can be plotted showing the individual losses in watts as a function of the voltages at constant excitation (see Fig. 229).

To determine the individual losses for various excitations, the experiment referred to above (current as a function of E.M.F. at constant excitation) is repeated with different excitations.

To separate the losses for different speeds and excitations by this method two groups of experiments are thus necessary, viz.—

(1) Measurement of the energy consumed by the armature at constant speed, variable excitation and variable terminal voltage (for $n =$ about $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{4}{4}$, and $\frac{5}{4}$ normal).

(2) Measurement of the current consumed at constant excitation and variable speed (variable terminal voltage)—for $n = \frac{1}{3}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{4}{4}$, and if possible $\frac{5}{4}$ normal.

About ten series of experiments are thus required. But as a matter of fact, the number can be considerably reduced, as several points on the curves in both groups of experiments would be repeated. It is quite sufficient to determine experimentally one group of curves, and to calculate the other group from the latter. As it is far easier to keep the voltage constant than the speed, it is best to determine by experiment the curves for constant excitation and variable speed.

For this purpose the machine must be connected up as shown in Fig. 199 and the exciting current adjusted to a maximum and kept constant. The speed is varied within very wide limits by means of the main regulator. Readings are then taken of the armature voltage, speed and the current consumed by the armature. Care should be exercised not to take readings before a stationary state with reference to the consumption of current is reached; this can easily be observed from the behaviour of the ammeter.

For accurate measurements accumulators should be used of sufficient capacity. For ordinary measurements the current may be derived from a dynamo; but even then variations of voltage should be avoided.

The following example shows how the experimental results are to be worked out:—

## Example XXVI.

*Separation of Losses by Dettmar's Method.*

The machine under test was a dynamo by Körting Bros. Voltage, 110; current, 550 amps. at 550 revolutions per minute; number of poles, 6. Total resistance of armature (at the temperature prevailing during the experiment), $0{\cdot}005\omega$.

The machine was run with various excitations ($c_m = 10, 7, 5{\cdot}5, 3, 1{\cdot}38$) and the corresponding values of E, $C_a$, and $n$ were observed.

TABLE OF RESULTS (I.).

| E | $C^a$ | $n$ |
|---|---|---|
| (*a*) Exciting current = 10 amps. | | |
| 98·5 | 30·54 | 358 |
| 77·5 | 26·72 | 281 |
| 61·8 | 28·88 | 223 |
| 47·35 | 21·2 | 172 |
| 23·35 | 17·25 | 84 |
| (*b*) Exciting current = 7 amps. | | |
| 99·55 | 32·4 | 423 |
| 77·48 | 28·0 | 336 |
| 61·18 | 24·8 | 266 |
| 39·0 | 20·26 | 167 |
| 18·8 | 16·68 | 80 |
| (*c*) Exciting current = 5·5 amps. | | |
| 99·7 | 33·84 | 509 |
| 77·0 | 29·2 | 396 |
| 60·7 | 25·6 | 308 |
| 35·0 | 19·87 | 177 |
| 19·5 | 16·76 | 98 |
| (*d*) Exciting current = 3 amps. | | |
| 97·99 | 43·56 | 783 |
| 71·55 | 35·2 | 575 |
| 52·9 | 29·9 | 426 |
| 21·1 | 20·08 | 168 |
| (*e*) Exciting current = 1·38 amps. | | |
| 47·85 | 55·4 | 730 |
| 31·0 | 42·6 | 476 |

From which results the following table is derived :—

TABLE OF RESULTS (II.).

| E | $C_a$ | $E - C_a r_a$ | $P = EC_a$ | $n$ | $\frac{E}{n}$ |
|---|---|---|---|---|---|
| | | (a) $c_m = 10$ amps. (I.). | | | |
| 98·5 | 30·54 | 98·35 | 3000 | 358 | 0·274 |
| 77·5 | 26·72 | 77·37 | 2065 | 281 | 0·275 |
| 61·8 | 23·88 | 61·68 | 1474 | 223 | 0·277 |
| 47·35 | 21·2 | 47·24 | 1000 | 172 | 0·274 |
| 23·35 | 17·84 | 23·26 | 415 | 84 | 0·276 |
| | | | | Average value of $\frac{E}{n}$ = | 0·275 |
| | | (b) $c_m = 7$ amps. (II.). | | | |
| 99·55 | 32·4 | 99·39 | 3220 | 432·3 | 0·23 |
| 77·48 | 28·0 | 77·34 | 2165 | 336·5 | 0·23 |
| 61·18 | 24·8 | 61·06 | 1513 | 266·3 | 0·23 |
| 39·0 | 20·26 | 38·9 | 788 | 167·6 | 0·232 |
| 18·8 | 16·68 | 18·72 | 312 | 80·4 | 0·233 |
| | | | | Average value of $\frac{E}{n}$ = | 0·231 |
| | | (c) $c_m = 5·5$ amps. (III.). | | | |
| 99·7 | 33·84 | 99·53 | 3370 | 509·5 | 0·196 |
| 77·0 | 29·2 | 76·85 | 2244 | 396·0 | 0·194 |
| 60·7 | 25·6 | 60·57 | 1550 | 308·0 | 0·197 |
| 35·0 | 19·87 | 34·9 | 693 | 177·8 | 0·197 |
| 19·55 | 16·76 | 19·47 | 326 | 98·5 | 0·197 |
| | | | | Average value of $\frac{E}{n}$ = | 0·196 |
| | | (d) $c_m = 3$ amps. (IV.). | | | |
| 97·99 | 43·56 | 97·77 | 4255 | 783·0 | 0·125 |
| 71·55 | 35·2 | 71·37 | 2510 | 575·8 | 0·124 |
| 52·9 | 29·9 | 52·72 | 1578 | 426·5 | 0·124 |
| 21·1 | 20·08 | 21·0 | 421 | 168·0 | 0·125 |
| | | | | Average value of $\frac{E}{n}$ = | 0·125 |

TABLE OF RESULTS (II.)—*continued.*

| E | $C_a$ | $E - C_a r_a$ | $P = EC_a$ | $n$ | $\frac{E}{n}$ |
|---|---|---|---|---|---|
| | | (*e*) $c_m = 1{\cdot}38$ amps. (V.). | | | |
| 47·85 | 55·4 | 47·57 | 2635 | 730 | 0·065 |
| 31·0 | 42·6 | 30·79 | 1312 | 476 | 0·065 |
| | | | | Average value of $\frac{E}{n}$ = | 0·065 |

Plotting the values of P (the no-load losses) as a function of E, the curves I.–V. in Fig. 230 are obtained.

To determine the friction curves we require first the curves

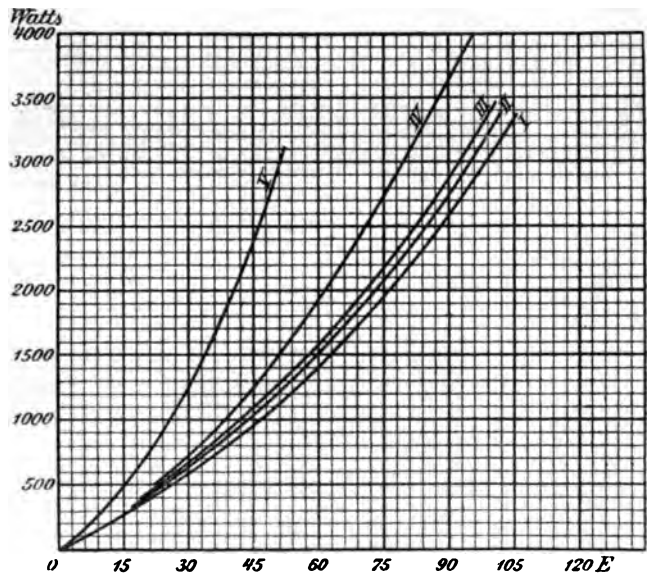



FIG. 230.

showing the no-load losses as function of E for constant speed, which can be calculated directly from Fig. 230. For this purpose in Table II. the values of $\frac{E}{n}$ are given for the various excitations. To find, for

instance, the no-load loss curve for $n = 150$ (constant), proceed as follows: For $c_m = 10$, $\frac{E}{n} = 0{\cdot}275$, thus $\frac{E}{n}.n = E = 41{\cdot}25$.

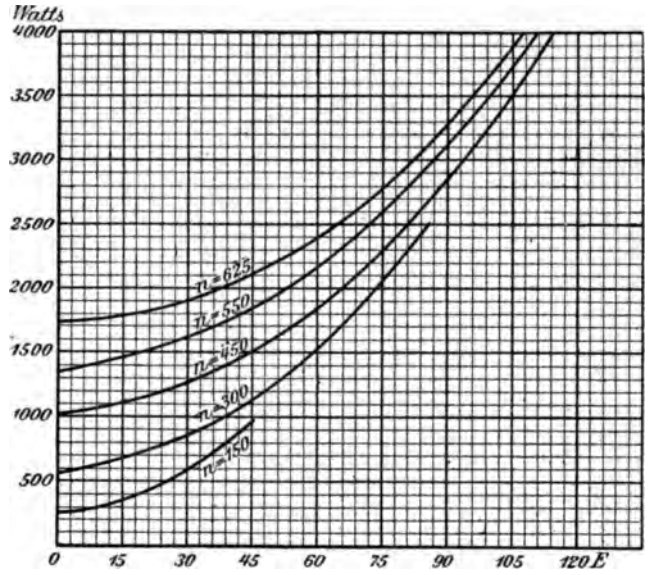



FIG. 231

From Fig. 230 we have for $c_m = 10$ and $E = 41{\cdot}25$ a loss of 830

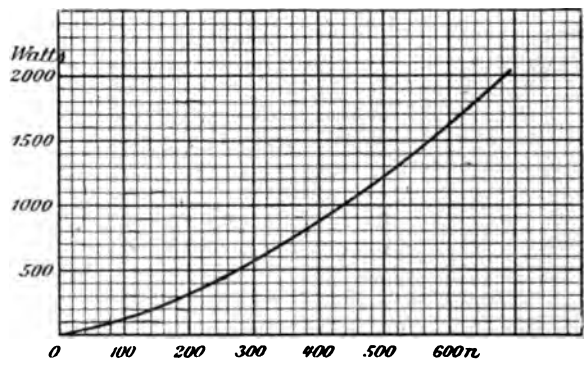



FIG. 232.

watts. For $c_m = 7$ amps. we find $\frac{E}{n}.n = 34{\cdot}6$, and for $E = 34{\cdot}6$,

P = 666. In the same manner proceed for other exciting currents. Thus we obtain for $n = 150$ constant a number of corresponding values for E and P, *i.e.* the required curve. Determine corresponding curves for a number of speeds (about $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{4}{4}$, and $\frac{5}{4}$ normal). In Fig. 231 the curves are plotted for $n = 150$, 300, 450, 550, and 625 revolutions per minute. The curves are produced to intersect the co-ordinate.

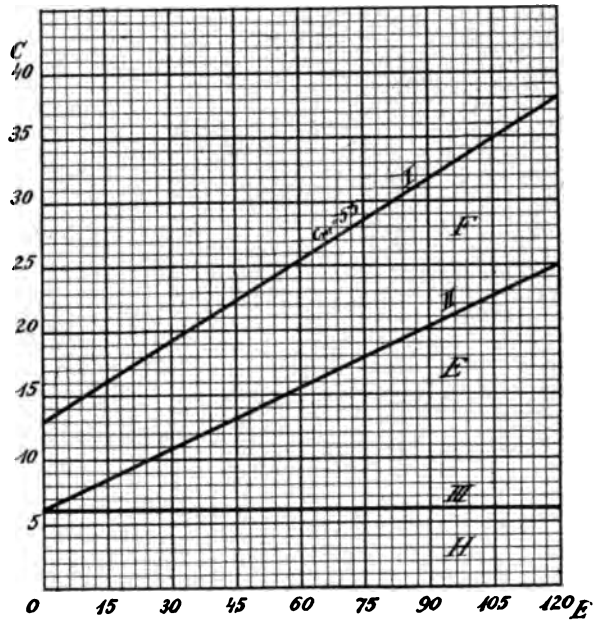



FIG. 233.

From Fig. 231 a curve can finally be drawn to represent the friction loss as a function of speed (see Fig. 232).

The further separation of losses may here be shown for the normal excitation only, *i.e.* for $c_m = 5{\cdot}5$. For this purpose in Fig. 233 (Curve I.) the armature current is plotted as a function of E, giving, as is usually the case, a straight line. The values are taken from Table II. (*c*). To find the currents corresponding to the friction losses for various voltages, find first the speeds corresponding to, say 100, 70, and 40 volts. For $c_m = 5{\cdot}5$—the constant $\frac{E}{n} = 0{\cdot}196$—and for—

100 volts, $n = 510$
70 „ $n = 357$
40 „ $n = 204$, etc.

According to Fig. 232 the friction loss for—

$n = 510$ is 1240 watts.
$n = 357$ „ 740 „
$n = 204$ „ 360 „

We can easily find the currents necessary to overcome the fric-

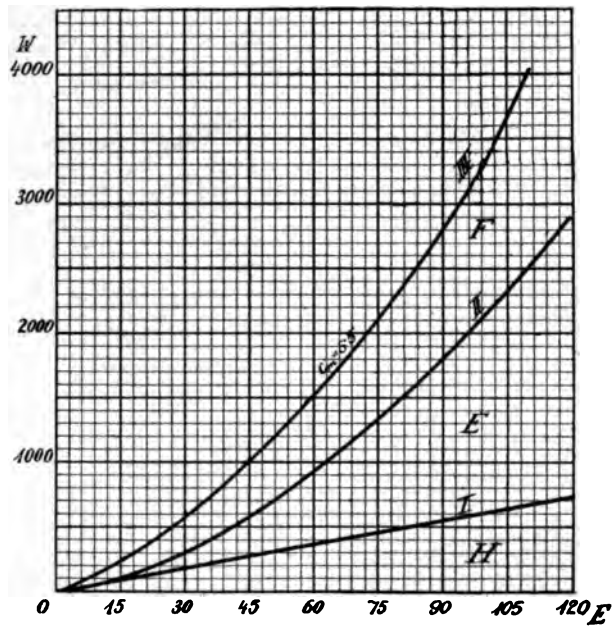



FIG. 234.

tional resistances for various values of E, since only a certain voltage corresponds to each speed for the given excitation (5·5 amps.).

Thus—

for $n = 510$, E = 100 v., friction loss in watts = 1240, and the current $\frac{1240}{100} = 12{\cdot}4$ amps.

„ $n = 357$, E = 70 v., „ „ = 740, and the current $\frac{740}{70} = 10{\cdot}6$ amps.

„ $n = 204$, E = 40 v., „ „ = 360, and the current $\frac{360}{40} = 9$ amps.

If the currents thus obtained are plotted in Fig. 233 from the ordinates of Curve I. downwards, Curve II. is obtained which represents the current—corresponding to the hysteresis + eddy-current losses—as a function of E. The point of intersection of II. with the ordinate represents the current corresponding to the hysteresis loss. To separate the two losses a straight line III. need only be drawn through the point of intersection parallel to the abscissa.

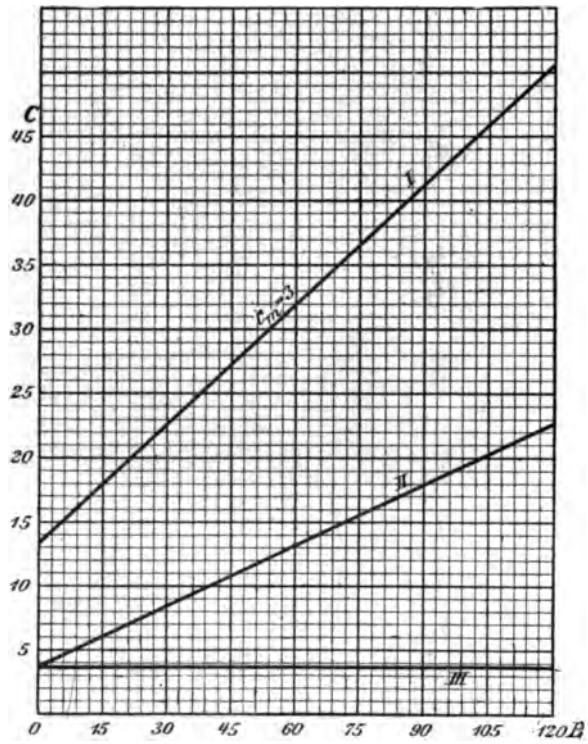



FIG. 235.

The nature of the individual losses becomes much clearer if they are plotted in watts as functions of E. Hence the currents need only be multiplied with the corresponding voltages, and the product (in watts) plotted as a function of the latter. This has been done in Fig. 234; Curves I., II., and III. represent the hysteresis, eddy-current, and friction losses respectively as functions of the voltage (or speed) at constant normal excitation of the machine.

If the separation of losses is performed in the way indicated for several excitations, the individual losses may then also be found for constant speed and variable excitation. Taking for instance $n = 550$ (normal) we would proceed as follows: For $c_m = 5{\cdot}5$ amps., $\frac{E}{n} = 0{\cdot}196$. Thus for $n = 550$, $E = 108$. According to Fig. 233 the current corresponding to the hysteresis loss is 6·2 amps. for the particular excitation, hence the hysteresis loss is $6{\cdot}2 \times 108 =$ about 670 watts.

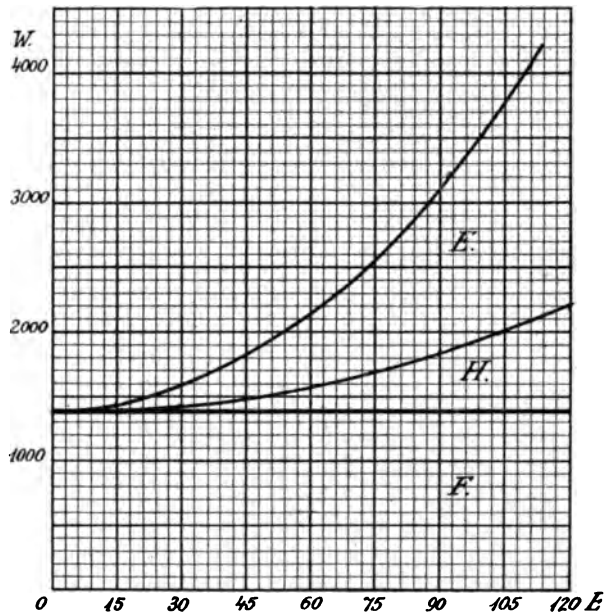



FIG. 236.

For $c_m = 3$ amps., $\frac{E}{n} = 0{\cdot}125$, therefore at $n = 550$, $E = 68{\cdot}5$ volts. Plotting the current diagram for this excitation (viz. $c_m = 3$ amps.) we find the current corresponding to the hysteresis loss is 3·6 amps. (see Fig. 235). Hence the hysteresis loss is equal to $3{\cdot}6 \times 68{\cdot}5$ = about 247 watts. The same should be repeated for two or three other exciting currents. The losses due to hysteresis are thus determined; the difference between the total no-load losses and the sum of the hysteresis and friction losses is equal to the eddy-current losses (in watts). The curves in Fig. 236 have been determined in this way.

The separation of losses for constant excitation can also be made

by calculation as shown on p. 248. For example, for a certain excitation of $c_m = 3$ the individual losses are determined and the no-load curve for $c_m = 3$ drawn from Fig. 230. For this excitation $\frac{E}{n} = 0{\cdot}125$, thus $n = \frac{E}{0{\cdot}125}$. We can then write down a scale of speeds on the

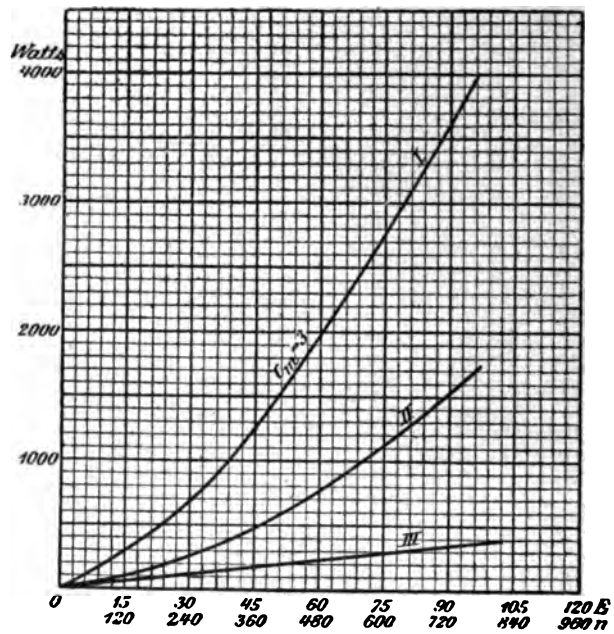



FIG. 237.

abscissa as well as a scale of E.M.F. This has been done in Fig. 237. Curve I. represents the total no-load losses. Subtracting the friction losses we obtain Curve II.—the magnetic losses. From this curve we find—

$$\text{for } n = 370 \quad .. \quad P = 460$$
$$\text{,, } n_1 = 720 \quad ... \quad P_1 = 1515$$

Since –

$$K_e = \frac{P_1 n - P n_1}{n_1^2 n - n^2 n_1} = \text{about } 0{\cdot}0023$$

the eddy-current losses will be—

$$\text{at } n = 370 \quad ... \quad 0{\cdot}0023 \times 370^2 = \text{about } 315 \text{ watts}$$
$$\text{,, } n_1 = 720 \quad ... \quad 0{\cdot}0023 \times 720^2 = \text{,, } 1190 \text{ ,,}$$

These two points give a straight line passing through the origin and representing the hysteresis losses.

In the same way the individual losses may be determined for any other excitation.

## 3. The "Inertia" Method

For larger machines (about 10 K.W. and upwards) the losses can very accurately be separated by the "inertia" method,* which is described in the following:—

The armature of the machine under test is first brought to as high a speed as possible, and then allowed by its own inertia to come to rest. The energy accumulated in the rotating armature will be spent in overcoming the resistances which oppose the rotation of the armature; the time which elapses between a certain speed and standstill of the armature gives a measure of the losses arising in the latter during its rotation. By running the armature first with the field excited and secondly without excitation, we can separate the mechanical from the magnetic losses. The latter can then be separated further by any of the methods described.

If we call—

$m$ the mass of the rotating armature (including commutator, belt-pulley, etc.),
$v_1$ the velocity of its centre of gravity at a time $t_1$,
$v_2$ the velocity of its centre of gravity at a time $t_2$,
$A_1$ the energy accumulated in the armature at a time $t_1$,

then—

$$A_1 = \frac{mv_1^2}{2}$$

if the armature has been brought to a speed $v_1$.

If $v_2$ is the velocity of the armature at a time $t_2$ when running with its own inertia, the energy still accumulated in the armature—

$$A_2 = \frac{mv_2^2}{2}$$

Hence the energy R, consumed during the time $t = t_2 - t_1$ is given by the equation—

$$R = A_1 - A_2 = \frac{m}{2}(v_1^2 - v_2^2) \quad . \quad . \quad . \quad . \quad . \quad (59)$$

* See Dettmar, *Elektrotechnische Zeitschrift*, 1899, p. 220; Peukert, 1901, p. 393.

Let $d$ = the diameter of the centre of gravity of the rotating part, and
$n_1$ and $n_2$ its respective speeds per minute,
then—

$$v_1 = \frac{d\pi n_1}{60}$$

$$v_2 = \frac{d\pi n_2}{60}$$

Let—

$$\frac{d\pi}{60} = c \text{ and } \frac{m}{2} = c_1$$

then—

$$R = c_1(c^2 n_1^2 - c^2 n_2^2) = c_1 c(n_1^2 - n_2^2)$$

Suppose $c_1 c^2 = C$

$$R = C(n_1^2 - n_2^2)$$

Hence the energy consumed per second—

$$r = \frac{R}{t} = \frac{C}{t}(n_1^2 - n_2^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad (60)$$

where—

$$C = \frac{m}{2}\left(\frac{d\pi}{60}\right)^2$$

If the constant C of the rotating part be known, it is easy to determine for a given period of time the energy consumed per second (namely, the losses arising in the armature at this period). The speed need only be measured in regular intervals. From these speeds and the intervals $t$, $r$ may be determined by means of formula (60).

The best method for determining the speed at regular intervals shall be dealt with later on.

If the cross-sections of the rotating body, *i.e.* of the armature, the commutator, and the belt-pulley were regular, C could be determined with great accuracy by calculation. But with an armature this is not the case, and makes the calculation of C hardly possible. C is easily obtained by experiment.

Obtaining first the loss curve of a machine, *i.e.* the curve representing the losses as a function of speed at constant excitation, and noting that the power consumed at any time $t$ will be equal to the losses in the armature at the particular period, and remembering that the latter comprise the mechanical and the magnetic losses, we have—

$$r = r_m + r_e$$

where $r_m$ = mechanical losses, $r_e$ = magnetic losses,

and—

$$r_m + r_e = \frac{C}{t}(n_1^2 - n_2^2)$$

thus—

$$C = \frac{t(r_m + r_e)}{n_1^2 - n_2^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (61)$$

For any interval of time $t$ we take $n_1$ and $n_2$ from a time curve determined with a constant excitation $c_m$. Then we determine by means of the no-load method $r_m + r_e$ for a speed $\frac{n_1 + n_2}{2}$ and for the same excitation. The smaller $t$, *i.e.* the smaller the difference between $n_1$ and $n_2$, the more accurate will be the determination of C. Though it is sufficient to find $r_m + r_e$ for a single speed to determine C, it is best to determine the complete curve of the magnetic losses, *i.e.* to determine $r_m + r_e$ as a function of $n$ at constant $c_m$. C may then be determined for a number of different speeds and the mean value taken.

When C is once determined, the separation of losses does not offer any difficulties. As mentioned above a time curve should be taken with the machine fully excited and another with the machine unexcited. If the corresponding loss curves are found from these time curves, the difference of the ordinates of the former will represent the magnetic losses at full excitation. To separate the latter we must either construct the current diagram, or else calculate the respective constants.

## Experiment No. XXVII

*Separation of Losses by the "Inertia" Method.*

Run the machine first with normal speed for several hours, and determine the no-load losses for various speeds at normal excitation. (With regard to this experiment, see p. 250.)

In making the actual experiment the machine must be brought to the normal, or better still, above the normal speed. This may be done in two ways: Either by running the machine as a motor, and after reaching the speed desired, breaking the main circuit; or (in many cases preferable) driving the machine by means of a small auxiliary motor and throwing the belt off quickly when the machine has reached the required speed. The latter method has the advantage that the speed may be increased above the normal *ad libitum*.

While the motor is running with a gradually decreasing speed, the latter must be measured at regular intervals. It is evident that a tachometer cannot be used for this purpose, as the energy consumed by such an instrument is far too great. A speed counter should be coupled to the machine, and the total number of revolutions read at regular intervals. Another way is to measure the speed electrically, as described in experiment No. VI. For this purpose the E.M.F. of the machine must be determined as a function of speed for the exciting currents for which the time curves are found.

## EXAMPLE XXVII.

*Separation of Losses ("Inertia" Method).*

Machine, No. 2618. Type and maker, Kolben, Prague. Number of poles, 4.

Voltage, 220; output, 15 B.H.P.; speed, 880 revolutions per minute.

The ratio of $\frac{n}{E}$ was first determined at various excitations.

$$\text{For } c_m = 1{\cdot}0, \frac{n}{E} = 4$$

$$c_m = 0{\cdot}6, \frac{n}{E} = 5{\cdot}7$$

$$c_m = 0, \frac{n}{E} = 275$$

From these the speed can be calculated from the voltage measured on the machine terminals.

Next the no-load losses were determined for $c_m = 1{\cdot}0$. The results are as follows:—

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Armature voltage, E ... | 222 | 182 | 168 | 156 | 106 | 77 | 59 |
| Armature current, $C_a$ ... | 4·9 | 4·7 | 4·5 | 4·45 | 4·35 | 4·2 | 4·12 |
| No-load losses, $EC_a - C_a^2 r_a$ | 1084 | 850 | 753 | 688 | 456 | 320 | 240 |
| Speed ... ... ... | 888 | 726 | 662 | 620 | 415 | 300 | 230 |

The time curves for $c_m = 1$, 0·6, and 0 (see Fig. 238) have been plotted from the following results:—

I. $c_m = 1{\cdot}0$

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time (seconds) | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 |
| Armature voltage | 220 | 190 | 160 | 131 | 105 | 77·5 | 52·5 | 27·5 | 2·5 |

II. $c_m = 0{\cdot}6$

| Time (seconds) | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Armature voltage | 154 | 139 | 124·5 | 112 | 97 | 82 | 67 | 56 | 43 | 29·8 | 17·6 | 6·15 |

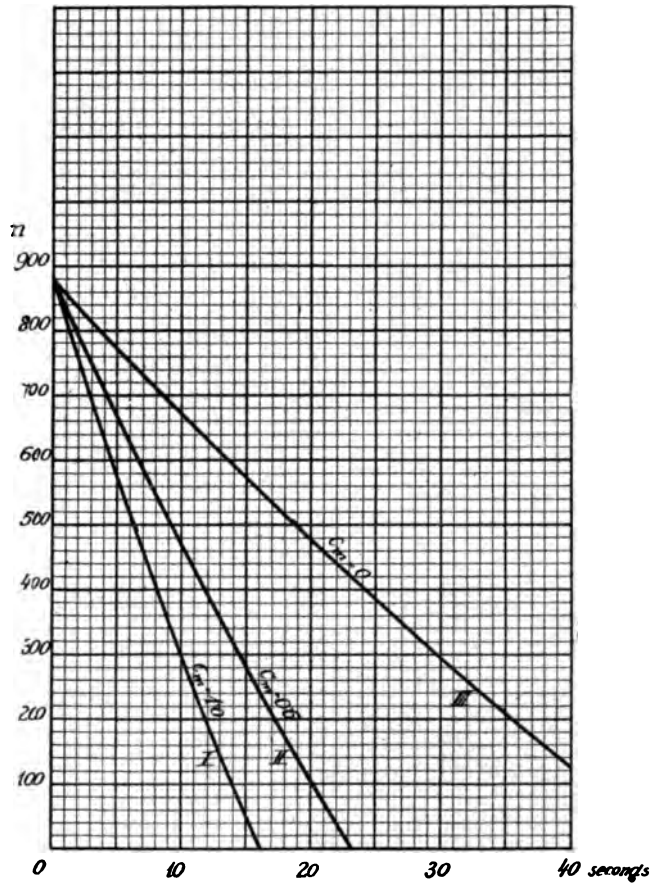



FIG. 238.

III. $c_m = 0$

| Time (seconds) | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Armature voltage | 3·2 | 3·05 | 2·9 | 2·75 | 2·6 | 2·44 | 2·3 | 2·17 | 2·02 | 1·86 | 1·75 |

| Time (seconds) | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|
| Armature voltage | 1·68 | 1·48 | 1·35 | 1·2 | 1·09 | 0·94 | 0·83 | 0·71 | 0·58 | 0·47 |

In Fig. 239, Curve I. shows the no-load losses; the time curves I.–III. are plotted in Fig. 238. The constant C is found by the formula—

$$C = \frac{tr}{n_1^2 - n_2^2}$$

where $r$ stands for the no-load losses at a speed $\frac{n_1 + n_2}{2}$.

For example: From the time Curve I. (Fig. 238), which is taken

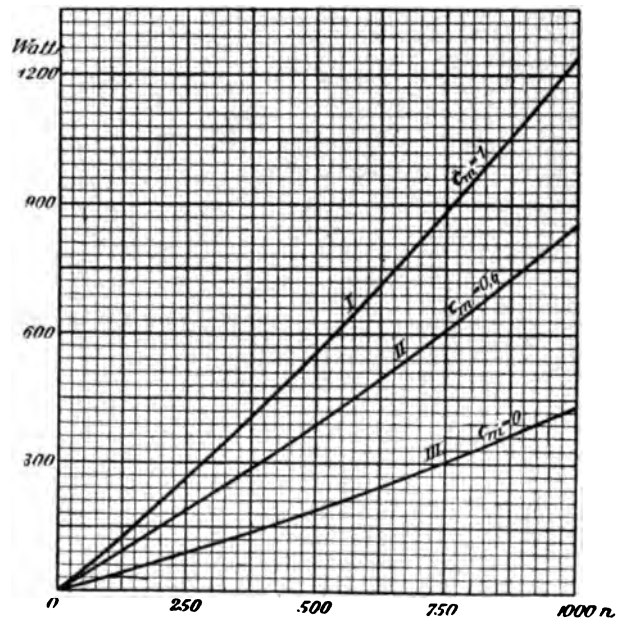



FIG. 239.

for $c_m = 1$ amp., we find for $n_1 = 880$ and $t = 1$, $n_2 = 820$. From Curve I. in Fig. 239 we find for $c_m = 1$ amp., and $n = \frac{880 + 820}{2} = 850$—a no-load loss of 1020 watts, thus—

$$C = \frac{1 \,.\, 1020}{880^2 - 820^2} = 0{\cdot}01$$

In this way C may be determined for a number of points, and the mean value taken; this mean value in our example is 0·01.

By means of this constant the loss curves can be constructed from the time curves.

For example: For $c_m = 0$, $n_1 = 300$, $n_2 = 280$, $t = 1$, the no-load loss (which as $c_m = 0$ corresponds to the mechanical loss)—

$$r = \frac{C}{t}(n_1^2 - n_2^2) = \frac{0{\cdot}01}{1}(300^2 - 280^2) = 116$$

hence for $c_m = 0$ and $n = 290$ the no-load loss is equal to 116 watts.

In this way Curves II. and III. in Fig. 239 have been determined.

# CHAPTER XI

# PRACTICAL TESTING OF CONTINUOUS CURRENT MACHINES

## Introduction

BEFORE a machine is sent out from the works, and in some cases after its installation, it should be thoroughly tested. The purpose of such a thorough test is twofold: Firstly, the machine should fulfil all the specified conditions (see the rules of the American Institute of Electrical Engineers), which will necessitate a several hours' run with full load, after which its temperature, insulation, and voltage (or speed) drop are tested, and if a specific efficiency is named it will require to be measured after the machine has reached its final temperature.

Secondly, the thorough test is to obtain in a systematic manner data for possible improvement of the various sizes and types of machines. These investigations (which are generally made with new types and sizes of machines) are too numerous to be described here; they will generally refer to constants involving, for instance, the ratio between the radiating surface, the peripheral speed, and the loss in the armature on the one hand, and its temperature on the other hand; also constants referring to sparking, etc.

With regard to the conditions which a machine has to fulfil, specifications are generally issued by the purchaser, and in some cases the rules drawn up by the Standardization Committee of the American Institute of Electrical Engineers are also adopted. These rules are here appended as far as they concern continuous current machines.

## 1. American Institute of Electrical Engineers

### Report of Committee of Standardization

The following rules have been adopted at the nineteenth annual meeting of the Institute of Electrical Engineers (June 20, 1902). (The definitions and rules referring to continuous current only are mentioned here.)

## Preliminary Definitions.

A direct current is an undirectional current.

A continuous current is a steady, or non-pulsating, direct current.

Electrical apparatus will be treated under the following headings:—

I. *Commutating Machines,* which comprise a constant magnetic field, a closed coil armature, and a multi-segmental commutator connected thereto.

Under this head may be classed the following: Continuous current generators; continuous current motors; continuous current boosters; motor generators; dynamotors; converters and closed-coil arc machines.

A booster is a machine inserted in series in a circuit to change its voltage, and may be driven either by an electric motor, or otherwise. In the former case it is a motor booster.

A motor generator is a transforming device consisting of two machines; a motor and a generator, mechanically connected together.

A dynamotor is a transforming device combining both motor and generator, acting in one magnetic field, with two armatures, or with an armature having two separate windings.

For converters, see III.

II. *Synchronous Machines,* which comprise a constant magnetic field, and an armature receiving or delivering alternating currents in synchronism with the motion of the machine; *i.e.* having a frequency equal to the product of the number of pairs of poles and the speed of the machine in revolutions per second.

III. *Synchronous Commutating Machines.*—These include (1) synchronous converters, commonly called "converters;" *i.e.* converters, from alternating to direct, or from direct to alternating current, and (2) double current generators; *i.e.* generators producing both direct and alternating currents.

A converter is a machine employing mechanical momentum in changing electric energy from one form into another.

A converter may be either:

(*a*) A direct current converter, converting from a direct current to a direct current.

(*b*) A synchronous converter, formerly called a rotary converter, converting from an alternating to a direct current, or *vice versâ.*

Phase converters are converters from an alternating current system to an alternating current system of the same frequency but in different phase.

Frequency converters are converters from an alternating current system of one frequency to an alternating current system of another frequency, with or without change in the number of phases.

IV. *Rectifying Machines or Pulsating Current Generators,* which produce an undirectional current of periodically varying strength.

V. *Stationary Induction Apparatus.*—(Alternating currents only.)

VI. *Rotary Induction Apparatus.*—(Alternating currents only.)

## EFFICIENCY.

1. The "efficiency" of an apparatus is the ratio of its net power output to its gross power input.

2. The efficiency of all apparatus, except such as may be intended for intermittent service, should be either measured at, or reduced to, the temperature which the apparatus assumes under continuous operation at full rated load, referred to a room temperature of 25° C.

With apparatus intended for intermittent service, the efficiency should be determined at the temperature assumed under specified conditions.

3. Electric power should be measured at the terminals of the apparatus.

4. In determining the efficiency of alternating-current apparatus, the electric power should be measured when the current is in phase with the E.M.F., unless otherwise specified, except when a definite phase difference is inherent in the apparatus, as in induction motors, induction generators, frequency converters, etc.

5. Mechanical power in machines should be measured at the pulley, gearing, coupling, etc., thus excluding the loss of power in said pulley, gearing, or coupling, but including the bearing friction and windage. The magnitude of bearing friction and windage may be considered as independent of the load. The loss of power in the belt and the increase of bearing friction due to belt tension, should be excluded. Where, however, a machine is mounted upon the shaft of a prime mover, in such a manner that it cannot be separated therefrom, the frictional losses in bearings and windage, which ought, by definition, to be included in determining the efficiency, should be excluded, owing to the practical impossibility of determining them satisfactorily. The brush friction, however, should be included.

Where a machine has auxiliary apparatus, such as an exciter, the power lost in the auxiliary apparatus should not be charged to the machine, but to the plant consisting of machine and auxiliary apparatus taken together. The plant efficiency in such cases should be distinguished from the machine efficiency.

6. The efficiency may be determined by measuring all the losses individually, and adding their sum to the output to derive the input, or subtracting their sum from the input to derive the output. All losses should be measured at, or reduced to, the temperature assumed in continuous operation, or in operation under conditions specified.

In order to consider the application of the foregoing rules to various machines in general use, the latter may be conveniently divided into classes as follows:—

## I. *Commutating Machines.*

7. In commutating machines the losses are—

(*a*) Bearing friction and windage.

(*b*) Molecular magnetic friction, and eddy currents in iron and copper, also $C^2r$ losses in cross-connections of cross-connected armatures. These losses should be determined with the machine on open circuit, and at a voltage equal to the rated voltage $+ Cr$ in a generator, and $- Cr$ in a motor, where C denotes the current strength and $r$ denotes the internal resistance of the machine. They should be measured at the correct speed and voltage, since they do not usually vary in any definite proportion to the speed or to the voltage.

(*c*) Armature resistance losses, $C^2r'$, where C is the current strength in the armature, and $r'$ is the resistance between armature brushes, excluding the resistance of brushes and brush contacts.

(*d*) Commutator brush friction.

(*e*) Commutator brush contact resistance. It is desirable to point out that with carbon brushes the losses (*d*) and (*e*) are usually considerable in low voltage machines.

(*f*) Field excitation. With separately excited fields, the loss of power in the resistance of the field coils alone should be considered. With shunt fields or series fields, however, the loss of power in the accompanying rheostat should also be included, the said rheostat being considered as an essential part of the machine, and not as separate auxiliary apparatus.

(*b*) and (*c*) are losses in the armature or "armature losses;" (*d*) and (*e*) "commutator losses;" and (*f*) "field losses."

8. The difference between the total losses under load and the sum of the losses above specified, should be considered as "load losses," and are usually trivial in commutating machines of small field distortion. When the field distortion is large, as is shown by the necessity for shifting the brushes between no load and full load, or with variations of load, these load losses may be considerable, and should be taken into account. This applies especially to constant current arc light generations. In this case the efficiency may be determined either by input and output measurement, or the load losses may be estimated by the method described later on.

9. Boosters should be considered and treated like other direct current machines in regard to losses.

10. In motor generators, dynamotors, or converters, the efficiency is the electric output divided by the electric input.

## II. *Synchronous Machines.*

(Alternating currents only.)

## III. *Synchronous Commutating Machines.*

13. In converters, the power on the alternating current side is to be measured with the current in phase with the terminal E.M.F. unless otherwise specified.

14. In double current generators, the efficiency of the machine should be determined as a direct current generator in accordance with section 7, and as an alternating current generator in accordance with 12. The two values of efficiency may be different, and should be clearly distinguished.

15. In converters the losses should be determined when driving the machine by a motor. These losses are—

(*a*) Bearing friction and windage.

(*b*) Molecular magnetic friction and eddy currents in iron, copper, and metallic parts, also $C^2r$ loss, due to cross-current in cross-connected armatures. These losses should be determined at open circuit and at the rated terminal voltage, no allowance being made for the armature resistance since the alternating and the direct current flow in opposite directions.

(*c*) Armature resistance. The loss in the armature is $qC^2r$, where C = direct current in armature, $r$ = armature resistance, and $q$ a factor which is equal to 1·47 in single-circuit single-phase, 1·15 in double-circuit single-phase, 0·59 in three-phase, 0·39 in four-phase, and 0·27 in six-phase converters.

(*d*) Load losses as defined in section 8. While these losses cannot well be determined individually, they may be considerable and, therefore, their joint influence should be determined by observation. This can be done by operating the machine on short-circuit or at full-load current, that is, by determining what may be called the "short-circuit core loss." With the low field intensity and great lag of current existing in this case, the load losses are usually greatly exaggerated.

One-third of the short-circuited core loss may, as an approximation, and in the absence of more accurate information, be assumed as the load loss.

(*e*) and (*f*) Losses in commutator and collector friction and brush contact resistance.

(*g*) Field excitation. In separately excited fields, the $C^2r$ loss in

the field coils proper should be taken, while in shunt and series fields the rheostat loss should be included, except where fields and rheostats are intentionally modified to produce effects outside of the conversion of electric power, as for producing phase displacement for voltage control. In this case 25 per cent. of the $C^2r$ loss in the field proper at non-inductive alternating circuit should be added as proper estimated allowance for normal rheostat losses.

16. Where two similar synchronous machines are available, their efficiency can be determined by operating one machine as a converter from direct to alternating, and the other as a converter from alternating to direct, connecting the alternating sides together, and measuring the difference between the direct current input, and the direct current output. This process may be modified by returning the output of the second machine through two boosters into the first machine and measuring the losses. Another modification is to supply the losses by an alternator between the two machines, using potential regulators.

### IV. *Rectifying Machines or Pulsating Current Generators.*

17. These include: Open-coil arc machines, constant-current rectifiers, constant-potential rectifiers.

The losses in open-coil arc machines are essentially the same as in Sections 7 to 10 (closed-coil commutating machines). In this case, however, the load losses are usually greater, and the efficiency should be measured by input and output test, using wattmeters for measuring the output. In alternating-current rectifiers, the output must be also measured by wattmeter and not by voltmeter and ammeter, since owing to the pulsation of current and E.M.F., a considerable discrepancy may exist between watts and volt-amperes, amounting to as much as 10 or 15 per cent.

18. In constant current rectifiers, transforming from constant-potential alternating to constant direct current, by means of constant-current transforming devices and rectifying commutators, the losses in the transformers are to be included in the efficiency, and have to be measured when operating the rectifier, since in this case the losses are generally greater than when feeding an alternating secondary circuit. In constant-current transforming devices, the load losses may be considerable, and, therefore, should not be neglected.

The most satisfactory method of determining the efficiency in rectifiers is to measure electric input and electric output by wattmeter. The input is usually inductive, owing to a considerable displacement and to wave distortion. For this reason the apparent efficiency should also be considered, since it is usually much lower

than the true efficiency. The power consumed by the synchronous motor or other source driving the rectifier should be included in the electric input.

### V. *Stationary Induction Apparatus.*

19-20. (For alternating currents only.)

### VI. *Rotary Induction Apparatus.*

21-24. (For alternating currents only).

### VII. *Transmission Lines.*

25. The efficiency of transmission lines should be measured with non-inducive load at the receiving end, and with the rated receiving pressure and frequency, also with sinusoidal impressed E.M.F.'s, except where expressly specified otherwise, and with the exclusion of transformers or other apparatus at the end of the line.

## Rise of Temperature.

### *General Principles.*

26. Under regular service conditions, the temperature of electrical machinery should never be allowed to remain at a point at which permanent deterioration of its insulating material takes place.

27. The rise of temperature should be referred to the standard conditions of a room temperature of 25° C., a barometric pressure of 760 mm., and normal conditions of ventilation ; that is, the apparatus under test should neither be exposed to draught nor enclosed, except where expressly specified.

28. If the room temperature during the test differs from 25° C., the observed rise of temperature should be corrected by ½ per cent. for each degree C. Thus with a room temperature of 35° C., the observed rise of temperature has to be decreased by 5 per cent., and with a room temperature of 15° C., the observed rise of temperature has to be increased by 5 per cent. The thermometer indicating the room temperature should be screened from thermal radiation emitted by heated bodies, or from draughts of air. When it is impracticable to secure normal conditions of ventilation on account of an adjacent engine, or other sources of heat, the thermometer for measuring the air temperature should be placed so as fairly to indicate the temperature which the machine would have if it were idle, in order that the rise of temperature determined shall be that caused by the operation of the machine.

29. The temperature should be measured after a run of sufficient duration to reach practical constancy. This is usually from six to eighteen hours, according to the size and construction of the apparatus. It is permissible, however, to shorten the time of the test by running a lesser time on an overload in current and voltage, then reducing the load to normal, and maintaining it thus until the temperature has become constant.

In apparatus intended for intermittent service, as railway motors, starting rheostats, etc., the rise of temperature should be measured after operation under as nearly as possible the conditions of service for which the apparatus is intended, and the conditions of the test should be specified.

In apparatus which by the nature of their service may be exposed to overload, as railway converters, and in very high voltage circuits, a smaller rise of temperature should be specified than in apparatus not liable to overloads or in low voltage apparatus. In apparatus built for conditions of limited space, as railway motors, a higher rise of temperature must be allowed.

30. In electrical conductors, the rise of temperature should be determined by their increase of resistance where practicable. For this purpose the resistance may be measured either by galvanometer test, or by drop of potential method. A temperature coefficient of 0·42 per cent. per degree C. from and at 0° C., may be assumed for copper.* Temperature elevations measured in this way are usually in excess of temperature elevations measured by thermometers.

When thermometers are applied to the free surface of a machine, it is desirable that the bulb of the thermometer should be covered by a pad of definite area. A convenient pad may be formed of cotton waste in a shallow circular box about 1½ inch in diameter, through a slot in the side of which the thermometer bulb is inserted. An unduly large pad over the thermometer tends to interfere with the natural liberation of heat from the surface to which the thermometer is applied.

31. With apparatus in which the insulating materials have special heat-resisting qualities, a high temperature elevation is permissible.

32. In apparatus intended for service in places of abnormally high temperature, a lower temperature elevation should be specified.

* By the formula—

$$R_t = R_0(1 + 0{\cdot}0042t) \text{ and}$$
$$R_{t+\theta} = R_0\{(1 + 0{\cdot}0042)(t + \theta)\}$$

where $R_t$ is the initial resistance at room temperature $t$° C.
$R_{t+\theta}$ is the final resistance at temperature elevation $\theta$° C.
$R_0$ is the inferred resistance at 0° C.

These combine into the formula—

$$\theta = (238{\cdot}1 + t)\left(\frac{R_{t+\theta}}{R_t} - 1\right) \text{ degrees C}$$

33. It is recommended that the following maximum of values of temperature elevation should not be exceeded:—

Commutating machines, rectifying machines, and synchronous machines—

Field and armature by resistance, 50° C.

Commutator and collector rings and brushes, by thermometer, 55° C.

Bearings and other parts of machine, by thermometer, 40° C.

Rotary induction apparatus—

Electric circuits, 50° C., by resistance.

Bearings and other parts of the machine, 40° C., by thermometer.

In squirrel-cage or short-circuited armatures, 55° C., by thermometer, may be allowed.

Transformers for continuous service—electric circuits by resistance, 50° C.; other parts by thermometer, 40° C., under conditions of normal ventilation.

Reactors, induction and magneto-regulators—electric circuits by resistance, 50° C.; other parts by thermometer, 40° C.

Where a thermometer, applied to a coil or winding, indicates a higher temperature elevation than that shown by resistance measurement, the thermometer indication should be accepted. In using the thermometer, care should be taken so to protect its bulb as to prevent radiation from it, and, at the same time, not to interfere seriously with the normal radiation from the part to which it is applied.

34. In the case of apparatus intended for intermittent service, except railway motors, the temperature elevation which is attained at the end of the period corresponding to the term of full load, should not exceed 50° C. by resistance in electric circuits. In the case of transformers intended for intermittent service, or not operating continuously at full load, but continuously in circuit, as in the ordinary case of lighting transformers, the temperature elevation above the surrounding air temperature should not exceed 50° C. by resistance in electric circuits and 40° C. by thermometer in other parts, after the period corresponding to the term of full load. In this instance, the test load should not be applied until the transformer has been in circuit for a sufficient time to attain the temperature elevation due to core loss. With transformers for commercial lighting, the duration of the full-load test may be taken as three hours, unless otherwise specified. In the case of railway, crane, and elevator motors, the conditions of service are necessarily so varied that no specific period corresponding to the full-load term can be stated.

35. The commercial rating of a railway motor should be the B.H.P. output giving 75° C. rise of temperature, above a room temperature of 25° C. after one hour's continuous run at 500 volts terminal pressure, on a stand, with the motor covers removed.

For determining the service temperature of a railway motor, the temperature rise should be determined by operating the motor on a straight and level track and under specified conditions—

(1) As to the load carried in tons per motor.

(2) The schedule speed in miles per hour.

(3) The number of stops per mile.

(4) The duration in seconds of the stops.

(5) The acceleration to be developed in miles per hour per second.

(6) The braking retardation to be developed in miles per hour per second.

These specifications should be determined, or agreed upon, as equivalent to the actual service, and the motors to be closed or open, according to the way in which they are to be operated in service.

The tests should be made in both directions over the same track.

By a "level track" should be understood a track in which the gradient does not exceed ½ per cent. at any point.

By a "straight track" should be understood a track in which the radius of curvature is nowhere less than the distance travelled by the car in thirty seconds, at the maximum speed reached during the run.

The wind velocity during a test should not exceed ten miles per hour in any test.

### Insulation.

36. The ohmic resistance of the insulation is of secondary importance only, as compared with the dielectric strength, or resistance to rupture by high voltage.

Since the ohmic resistance can be very greatly increased by baking, but the dielectric strength is liable to be weakened thereby, it is preferable to specify a high dielectric strength rather than a high insulation resistance. The high-voltage test for dielectric strength should always be applied.

### Insulation Resistance.

37. Insulation resistance tests should, if possible, be made at the pressure for which the apparatus is designed.

The insulation resistance of the complete apparatus must be such that the rated voltage of the apparatus will not send more than 1/1,000,000 of the full-load current through the insulation. Where the value found in this way exceeds 1 megohm, 1 megohm is sufficient.

### Dielectric Strength.

38. The dielectric strength or resistance to rupture should be determined by a continued application of an alternating E.M.F. for one minute. The source of alternating E.M.F. should be a transformer of such size that the charging current of the apparatus as a condenser does not exceed 25 per cent. of the rated output of the transformer.

39. In alternating-current apparatus, the test should be made at the frequency for which the apparatus is designed.

40. The high-voltage tests should not be applied when the insulation is low, owing to dirt or moisture, and should be applied before the machine is put into commercial service.

The high-potential test should be made at the temperature assumed under normal operation, as specified under "Efficiency."

41. It should be pointed out that tests at high voltages considerable in excess of the normal voltages, to determine whether specifications are fulfilled, are admissible on new machines only.

42. The test for dielectric strength should be made with the completely assembled apparatus and not with its individual parts, and the voltage should be applied as follows:—

(1) Between electric circuits and surrounding conducting material, and

(2) Between adjacent electric circuits, where such exist, as in the transformer.

The tests should be made with a sine wave of E.M.F., or where this is not available, at a voltage giving the striking distance between needle points in air, as a sine wave of the specified E.M.F., except where expressly specified otherwise. As needles, new sewing needles should be used. It is recommended to shunt the apparatus during the test by spark gap of needle points set for a voltage exceeding the required voltage by 10 per cent.

A table of approximate sparking distances is given at the end.

43. The following voltages are recommended for apparatus not including transmission lines or switchboards :—

| Rated terminal voltage. | Rated output. | Testing voltage. |
|---|---|---|
| Not exceeding 400 volts | Under 10 K.W. | 1,000 volts |
| " " 400 " | 10 K.W. and over | 1,500 " |
| Over 400 but less than 800 " | Under 10 K.W. | 1,500 " |
| " 400 " " 800 " | 10 K.W. and over | 2,000 " |
| " 800 " " 1,200 " | Any | 3,500 " |
| " 1,200 " " 2,500 " | " | 5,000 " |

| Rated terminal voltage. | Rated output. | Testing voltage. |
|---|---|---|
| Over 2,500 but less than 10,000 volts | Any | Double the normal rated voltage |
| „ 10,000 „ „ 20,000 „ | „ | 10,000 volts above normal rated voltage |
| „ 20,000 volts | „ | 50 % above normal rated voltage. |

Except that transformers of 5000 volts or less, directly feeding consumption circuits should be tested at 10,000 volts.

Synchronous motor fields and fields of converters started from the alternating current side, 5000 volts.

Alternator field circuits should be tested under a breakdown test voltage corresponding to the rated voltage of the exciter, and referred to an output equal to the output of the alternator; *i.e.* the exciter should be rated for this test as having an output equal to that of the machine it excites.

Condensers should be tested at twice their rated voltage and at their rated frequency.

The values in the table above are effective values, or square roots of mean square, reduced to a sine wave of E.M.F.

44. In testing insulation between different electric circuits, as between primary and secondary of transformers, the testing voltage must be chosen corresponding to the high-voltage circuit.

45. In transformers of 20,000 volts upwards, it should be sufficient to test the transformer by operating it at 50 per cent. above its rated voltage; if necessary, with sufficiently higher frequency to induce this voltage.

46. The test of the insulation of a transformer, if no testing transformer is available, may be made by connecting one terminal of the high-voltage winding to the core and low-voltage winding, and then repeating the test with the other terminal of the high-voltage winding so connected. The test of the dielectric resistance between the low-voltage winding and the core should be in accordance with the recommendation in Section 43, for similar voltages and capacities.

47. High-voltage tests on transformers or other apparatus should be based upon the voltages between the conductors of the circuit to which they are connected.

48. When machines or apparatus are to be operated in series, so as to employ the sum of their separate E.M.F.'s, the voltage should be referred to this sum, except where the frames of the machines are separately insulated both from the ground and from each other.

The insulation between machines and between each machine and ground should be tested, the former referred to the voltage of one machine, and the latter to the total voltage of the series.

49. Underground cables, and line switches, should be tested by the application of an alternating E.M.F. for one minute at twice the voltage at which the cable or switch is to be operated.

## REGULATION.

50. The term "regulation" should have the same meaning as the term "inherent regulation" at present frequently used.

51. The regulation of an apparatus intended for the generation of constant potential, constant current, constant speed, etc., is to be measured by the maximum variation of potential, current, speed, etc., occurring within the range from full load to no load, under such constant conditions of operation as give the required full-load values, the condition of full load being considered in all cases as the normal condition of operation.

52. The regulation of an apparatus intended for the generation of a potential, current, speed, etc., varying in a definite manner between full load and no load, is to be measured by the maximum variation of potential, current, speed, etc., from the satisfied condition, under such constant conditions of operation as give the required full-load values.

If the manner in which the variation in potential, current, speed, etc., between full load and no load is not specified, it should be assumed to be a simple linear relation; *i.e.* undergoing uniform variation between full load and no load.

The regulation of an apparatus may, therefore, differ according to its qualifications for use. Thus, the regulation of a compound-wound generator specified as a constant-potential generator, will be different from that it possesses when specified as an over-compound generator.

53. The regulation is given in percentage of the full-load value of potential, current, speed, etc., and the apparatus should be steadily operated during the test under the same conditions as at full load.

54. The regulation of generators is to be determined at constant speed, of alternating apparatus at constant impressed frequency.

55. The regulation of a generator unit, consisting of a generator united with a prime mover, should be determined at constant

conditions of the prime mover; *i.e.* constant steam pressure, head, etc. It would include the inherent speed variations of the prime mover. For this reason the regulation of a generator unit is to be distinguished from the regulation of either the prime mover, or of the generator contained in it, when taken separately.

56. In apparatus generating, transforming, or transmitting alternating currents, regulation should be understood to refer to non-inductive load; that is, to a load in which the current is in phase with the E.M.F. at the output side of the apparatus, except where expressly specified otherwise.

57. In alternating apparatus receiving electric power, regulation should refer to a sine wave of E.M.F., except where expressly specified otherwise.

58. In commutating machines, rectifying machines, and synchronous machines, as direct current generators and motors, alternating current and polyphase generators, the regulation is to be determined under the following conditions:—

(*a*) At constant excitation in separately excited fields,

(*b*) With constant resistance in shunt field circuits, and

(*c*) With constant resistance shunting series fields; *i.e.* the field adjustment should remain constant, and should be so chosen as to give the required full-load voltage at full-load current.

59. In constant potential machines, the regulation is the ratio of the maximum difference of terminal voltage from the rated full-load value (occurring within the range from full load to open circuit) to the full-load terminal voltage.

60. In constant-current apparatus, the regulation is the ratio of the maximum difference of current from the rated full-load value (occurring within the range from full load to short circuit, or minimum limit of operation) to the full-load current, at constant speed; or in transformers, etc., at constant impressed voltage and frequency.

61. In constant-power apparatus, the regulation is the ratio of maximum difference of power from the rated full-load value (occurring within the range of operation specified) to the rated power.

62. In over-compounded machines, the regulation is the ratio of maximum difference in voltage from a straight line connecting the no-load and full-load values of terminal voltage as function of the current to the full-load terminal voltage.

63. In constant-speed, continuous-current motors, the regulation is the ratio of the maximum variation of speed from its full-load value (occurring within the range from full-load to no-load) to the full-load speed.

64. In constant-potential non-inductive transformers, the regulation is the ratio of the rise of secondary terminal voltage from full

load to no load (at constant primary impressed terminal voltage) to the secondary terminal voltage.

65. In induction motors, the regulation is the ratio of the rise of speed from full load to no load (at constant impressed voltage) to the full speed.

The regulation of an induction motor is, therefore, not identical with the slip of the motor, which is the ratio of the drop in speed from synchronism to the synchronous speed.

66. In converters, dynamotors, motor generators, and frequency converters, the regulation is the ratio of the maximum difference of terminal voltage at the output side from the rated full-load voltage (at constant impressed voltage and at constant frequency) to the full-load voltage on the output side.

67. In transmission lines, feeders, etc., the regulation is the ratio of maximum voltage difference at the receiving end, between no-load and full non-inductive load, to the full-load voltage at the receiving end, with constant voltage impressed upon the sending end.

68. In steam engines, the regulation is the ratio of the maximum variation of speed in passing from full load to no load (at constant steam pressure at the throttle) to the full-load speed.

69. In a turbine or other water-motor, the regulation is the ratio of the maximum variation of speed from full load to no load (at constant head of water, *i.e.* at constant difference of level between tail race and head race) to the full-load speed.

70. In alternating-current apparatus, in addition to the non-inductive regulation, the impedance ratio of the apparatus should be specified ; *i.e.* the ratio of the voltage consumed by the total internal impedance of the apparatus at full-load current, to its rated full-load voltage. As far as possible a sinusoidal current should be used.

### Variation and Pulsation.

72. In prime movers which do not give an absolute uniform rate of rotation or speed, as in steam engines, the "variation" is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution as 360°; and the pulsation is the ratio of the maximum change of speed in an engine cycle to the average speed.

73. In alternators or alternating current circuits in general, the variation is the maximum difference in phase of the generated wave of E.M.F. from a wave of absolutely constant frequency, expressed in degrees, and is due to the variation of the prime mover. The pulsation is the ratio of the maximum change of frequency during an engine cycle to the average frequency.

74. If $n$ = number of poles, the variations of an alternator is $\frac{n}{2}$ times the variation of its prime mover, if directly connected, and $\frac{n}{2p}$ times the variation of the prime mover if rigidly connected thereto in the velocity ratio $p$.

## Rating.

75. Both electrical and mechanical power should be expressed in kilowatts, except when otherwise specified. Alternating current apparatus should be rated in kilowatts on the basis of non-inductive conditions; *i.e.*, with the current in phase with the terminal voltage.

76. Thus the electric power generated by an alternating-current apparatus equals its rating only at non-inductive load.

77. Apparent power should be expressed in kilovolt-amperes as distinguished from real power in kilowatts.

78. If a power-factor other than 100 per cent. is specified, the rating should be expressed in kilovolt-amperes and power factor at full load.

79. The full-load current of an electric generator is that current which with the rated full-load terminal voltage gives the rated kilowatts, but in alternating current apparatus only at non-inductive load.

80. Thus, in machines in which the full-load voltage differs from the no-load voltage, the full-load current should refer to the former.

If P = rating of an electric generator and E = full-load terminal voltage, the full-load current is—

$I = \frac{P}{E}$ in a continuous-current machine or single-phase alternator

$I = \frac{P}{E\sqrt{3}}$ in a three-phase alternator

$I = \frac{P}{2E}$ in a quarter-phase alternator

81. Constant-current machines, such as series arc-light generators should be rated in kilowatts based on terminal volts and amperes at full load.

82. The rating of a fuse or circuit breaker should be the current strength which it will continually carry. In addition thereto, the current strength at which it will open the circuit should be specified.

### Classification of Voltages and Frequencies.

83. In direct-current, low-voltage generators, the following average terminal voltages are in general use and are recommended—

125 volts 250 volts 550 to 600 volts

84. In direct-current and alternating current low-voltage circuits, the following average terminal voltages are in general use and are recommended :—

110 volts 220 volts

In direct-current power circuits, for railway and other service, 500 volts may be considered as standard.

85–88. (Alternating currents only.)

### Overload Capacities.

89. All guarantees on heating, regulation, sparking, etc., should apply to the rated load, except where expressly specified otherwise, and in alternating-current apparatus to the current in phase with the terminal voltage, except where a phase displacement is inherent to the apparatus.

90. All apparatus should be able to carry the overload specified in Section 92, without self-destruction by heating, sparking, mechanical weakness, etc., and with an increase in temperature elevation not exceeding 15°C., above those specified for full loads, the overload being applied after the apparatus has acquired the temperature corresponding to the full-load continuous operation.

91. Overload guarantees should refer to normal conditions of operation regarding speed, frequency, voltage, etc., and to non-inductive conditions in alternating apparatus, except where a phase displacement is inherent in the apparatus.

92. The following overload capacities are recommended :—

(1) In direct-current generators and alternating-current generators, 25 per cent. for two hours.

(2) In direct-current motors, induction motors, and synchronous motors, not including railway motors and other apparatus intended for intermittent service, 25 per cent. for two hours, and 50 per cent. for one minute, for momentary overload capacity.

(3) Synchronous converters, 50 per cent. for one half-hour.

(4) Transformers, 25 per cent. for two hours. Except in transformers connected to apparatus for which a different overload is guaranteed, in which case the same guarantees shall apply for the transformers as for the apparatus connected thereto.

(5) Exciters of alternators and other synchronous machines, 10 per cent. more overload than is required for the excitation of the synchronous machine at its guaranteed overload, and for the same period of time.

(7) All exciters of alternating-current, single-phase, or polyphase generators should be able to give at constant speed, sufficient voltage to excite the alternator at the rated speed, to the full-load terminal voltage, at the rated output in kilovolt-amperes and with 50 per cent. power factor.

93–98. *Luminous Sources.*

## Appendix I.

*Efficiency of Phase-Displacing Apparatus.*

## Appendix II.

*Apparent Efficiency.*

## Appendix III.

*Power Factor and Inductance Factor.*

## Appendix IV.

The following notation is recommended:—

E, *e*, voltage, E.M.F., potential difference.
I, *i*, current.
P, Power.
$\phi$, magnetic flux.
B, magnetic density.
R, *r*, resistance.
X, reactance.
Z, *z*, impedance.
L, *l*, inductance.
C, *c*, capacity.
Y, *y*, admittance.
*b*, susceptance.
*g*, conductance.
Vector quantities should be denoted by capital italics.

APPENDIX V.

*Table of Sparking Distances in Air between Opposed Sharp Needle Points for Various Effective Sinusoidal Voltages, in Inches and in Centimeters.*

| Kilovolts square root of mean square. | Distance. | |
|---|---|---|
| | Inches. | Cms. |
| 5 | 0·225 | 0·57 |
| 10 | 0·47 | 1·19 |
| 15 | 0·725 | 1·84 |
| 20 | 1·0 | 2·54 |
| 25 | 1·3 | 3·3 |
| 30 | 1·625 | 4·1 |
| 35 | 2·0 | 5·1 |
| 40 | 2·45 | 6·2 |
| 45 | 2·95 | 7·5 |
| 50 | 3·55 | 9·0 |
| 60 | 4·65 | 11·8 |
| 70 | 5·85 | 14·9 |
| 80 | 7·1 | 18·0 |
| 90 | 8·35 | 21·2 |
| 100 | 9·6 | 24·4 |
| 110 | 10·75 | 27·3 |
| 120 | 11·85 | 30·1 |
| 130 | 12·95 | 32·9 |
| 140 | 13·95 | 35·4 |
| 150 | 15·0 | 38·1 |

## 2. Shop Tests

After a machine is built it should be taken into the test room to be thoroughly tested. The shop tests should include: A continuous run with full load, and observations on the behaviour of the machine at overloads, and also the determination of the strength of its insulation. Besides these tests, which should be made with all machines irrespective of type and function, a few special tests will have to be made with the different types.

If the machine has been found satisfactory, it is given a finish and made ready for dispatch. Before packing the machine, it is advisable to make sure that no damage has taken place to the winding during the process of finishing. For this purpose it will be quite sufficient to run the machine light as a motor with normal voltage, and to measure its speed. If this is equal to the speed which the machine attained during the first test, and if there are no special symptoms after half an hour's run, then the machine is in good order. This short test may be made either in the test-room or the workshop.

It is recommended to provide each machine with a test-card which should contain the number of the machine, order No., etc., and any specifications with regard to the machine. A column should be provided in which the date and the results of the first test are entered, also directions for repairing or any alterations required. The next column is for the workshop; in this, remarks should be made with reference to alterations, etc. Finally, in the last column, the date of the final test, its result, and whether the machine is ready for dispatch, should be entered.

With very large machines, which cannot be tested in the test-room, the armature and field resistances should be at least measured, and the strength of the insulation tested. Such machines can also be tested in the way indicated in Chapter I, *i.e.* by short-circuiting the armature and weakly exciting the field. When possible a complete test should be made after the machine has been installed in its place, and the test entered up in the record book.

It may be mentioned that it is not usual to have different forms in the record book for the different types of machines, *i.e.* series, shunt, compound machines, tram motors, etc. Generally one form suffices for continuous current machines. The curves obtained should be drawn in a special book, and reference made in the record of the test to the respective page in the curve book.

The appendix contains a few specimens of record sheets from various English and Continental firms.

In the following are described the shop tests which should be made with the respective machines.

## 3. Shunt Generators

We shall deal first with generators for lighting and power transmission. The voltage of such machines must be kept constant or nearly constant for all loads.

The machine is first tested with full load at normal speed for

several hours. The purpose of this test is twofold. Firstly, we see whether the overheating of the machine exceeds a certain specified value or not, and secondly, whether the machine is really capable of giving its full load or any overload which may be specified. It may happen that a machine just gives its full output when cold, and that its maximum output when hot is below the specified amount.

With regard to the length of time the machine has to run with full load, we refer to the Rules of the Am.Inst.E.E. With small machines—up to, say, 5 K.W.—4–5 hours are mostly sufficient; with machines of medium size—up to 50 K.W.—6–8 hours; and with machines of more than 50 K.W., 10 or more hours will be required to reach a stationary state of overheating.

It need not be specially mentioned that the working conditions of the machine during the test should as far as possible be the same as during the actual working. It should run with normal voltage and speed, and tested with its own pulley.

In test-rooms continuous current dynamos are generally loaded in the way described in Chapter I., namely, they are worked either directly or in series with resistances on the supply mains. The voltage of the latter should, of course, be as constant as possible, as a variation of voltage would cause a variation of load of the dynamo under test. It will be also necessary to regulate the load from time to time by means of the shunt regulator—as with increasing temperature of the machine its load will gradually decrease.

Before loading the dynamo (main circuit open, and in cold state) its voltage should be adjusted to normal by means of the shunt regulator and the shunt current measured. The regulating resistance should then be short-circuited (the field terminals connected directly to the armature terminals), and again the shunt current and armature voltage measured and recorded.

During the permanent run the temperature of the room should be measured, say every half-hour, at a distance of about 3 feet from and in line with the centre of the armature.

Immediately after the permanent run the temperature of the machine must be measured. For this purpose the resistance of the field when cold should be known. The best plan is to have an ammeter in the shunt circuit, and to connect the voltmeter with a voltmeter switch so that the pressure across the field terminals as well as the armature voltage can be measured. From the field current and the field voltage the resistance can then be computed. It is advisable to take these readings about every half-hour, and during the test plot a curve showing the temperature relation of the field coils with time. From this curve it will then be seen if the temperature reached is the final.

The temperature of the armature may be found purely by measuring the armature resistance when hot and cold, even though the temperature be measured by means of a thermometer. For this measurement the indirect method suffices. The voltage should be measured across the machine terminals, the brushes, and the commutator. From this measurement any fault in the winding or the brushes would immediately become apparent.

If any fault exists in the machine, it will generally be found out during (or after) the permanent run. The faults which may cause a new machine to fail to generate, or to spark, etc., are too numerous to be described here. For information regarding them, the author's work * on "The Diseases of Electrical Machinery" may be consulted.

After the temperature is measured, an insulation test should be made, and the insulating strength of the machine tested. The voltages which should be employed at these tests are given in the Rules of the Am.Inst.E.E.

As a rule C.C. armatures for voltages up to 220 are tested with 500 volts A.C.; for more than 220 volts with 1000 volts A.C.

As it is impracticable to take the machine (after the load test) into a special high-tension room to test the dielectric strength of its insulation, it is advisable to have a few portable transformers with a variable ratio of transformation. These transformers can then be connected by means of plugs to the A.C. supply; their secondary voltage to be variable between 500 and 10,000.

After the permanent load run and the insulating test, the special tests which refer to the overload capacity, commutation, and determination of shunt resistance should be made.

For determining the overload capacity the machine should be brought to the normal (specified) speed. The shunt circuit is then closed and the voltage adjusted to normal. The voltage and exciting current should be recorded. The machine is next gradually loaded—the terminal voltage being kept constant by regulating the exciting current. For a number of different loads the corresponding exciting currents should be recorded. With regard to the brush position the brushes should be left in the neutral zone provided no sparking occurs. If sparking arises at larger loads the brush-rocker should be moved gradually, its position marked with chalk, and a remark be duly entered in the record sheet.

The load of the machine should be increased to at least 50 per cent. above the normal. If possible, however, it should be increased for a very short time to such an extent as to reach the sparking limit.

In some cases it may happen that at the specified speed the machine just develops its normal output or even a slight overload.

* "The Diseases of Electrical Machinery," by C. Kinzbrunner, Harper & Bros., London.

In such a case the output should still be increased a little by raising the speed. This is of course allowable with machines for belt or rope driving only, provided that the increase in speed is not considerable. The belt-pulley should therefore be made after the test is complete, when it has to be decided whether the diameter of the pulley should be made normal, or (according to the altered speed) with a smaller or larger diameter.

With machines for direct coupling with the prime mover, an alteration of the speed is of course impossible. If, with such a machine the specified output cannot quite be obtained, then two things can be done: either the armature or the field magnet coils can be re-wound. In most cases the latter will be preferable; but before re-winding the magnets, one must make sure that an increase of the field ampere-turns is possible without an undue overheating. Therefore proceed as follows: Separately excite the dynamo, and increase the exciting voltage until the dynamo has reached the requisite voltage (output). With this voltage run the machine for several hours and observe the overheating of the field coils. It will then be evident whether a re-winding of the field magnets is permissible or not. The ampere-turns increase—within certain limits—proportionally with the area of the magnet wires (a constant winding space being assumed); the cross-sectional area of the wire must hence be increased in the proportion of the ampere-turns. If an increase of the field ampere-turns is not permissible, there is nothing else but to re-wind the armature. In some cases it will be useful to insert a wrought-iron sheet between poles and pole-shoes; the air gap is thus reduced, and consequently an increase of the induction, *i.e.* an increase of voltage (output), obtained for the same speed.

It is useful to know the maximum voltage of a dynamo at normal speed. This will obviously be produced with no load and with the field coils cold and the regulating resistance cut out. This voltage should be measured before the machine is loaded.

Lastly, it is important to find the resistance of the shunt regulator. We know that the voltage of a shunt dynamo drops with increasing load owing to armature ohmic drop and armature reaction. The field coils are consequently designed so that the terminal voltage reached at no load is considerable, and that reached at full load somewhat above the normal terminal voltage. The latter is essential because the machine might be required to work in a room, the temperature of which may be higher than that prevailing in the test-room.

To determine the maximum resistance of the shunt regulator, the machine must run in the cold state with normal voltage, and the shunt current measured. From this particular shunt current and the known resistance of the field magnets the resistance of the shunt regulator is calculated. Let $c_m$ be the shunt current at no load with

field coils cold, $r_m$ their resistance, and $r_r$ the resistance of the required shunt regulator, then—

$$r_r = \frac{E}{c_m} - r_m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (62)$$

The resistance found by the above formula would just suffice to reduce the voltage of the unloaded cold dynamo to its normal value; but it would not be further sufficient if the speed of the dynamo were a little above the normal. To allow for such cases and to make the resistance of sufficient amount, a certain percentage, usually about 30–50 per cent. is added to the resistance found by the above formula.

With shunt regulators for smaller machines the subdivision of the resistance between adjacent stops is usually made to a standard scheme. With large machines, however, it is frequently of importance to keep the terminal voltage constant within certain limits ($\pm x$ per cent. of the normal voltage). It may happen with a regulator, the resistance of whose steps has not been specially determined, that with the lever on a certain stop the voltage is below the limit permissible, and on the next stop the maximum is exceeded. In such cases the resistance of the individual steps as well as the total resistance of the regulator should be determined.

The experiment which determines these resistances must be made when the machine is hot. The no-load characteristic and load characteristics for about $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{4}{4}$, and $\frac{5}{4}$ normal load should be determined with normal speed. The determination of the load characteristics has been discussed in Chapter VII. In the present case it is unnecessary to determine the complete curves — only the part in the neighbourhood of the normal voltage is required. In Fig. 240, Curve I. represents the no-load characteristic, Curves II., III., IV., V., and VI. represent the load characteristics of a 90 K.W. generator for $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{4}{4}$, and $\frac{5}{4}$ normal load respectively.

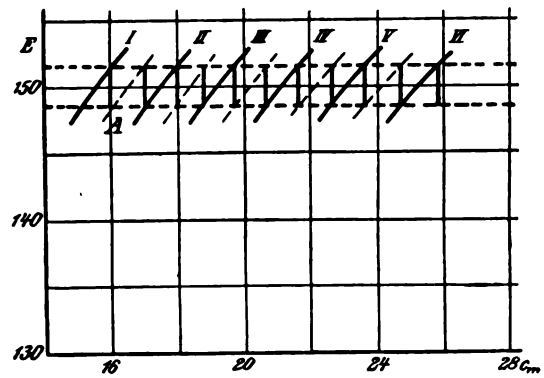



FIG. 240.

The resistances are found as follows: Assuming the voltage is kept constant within ± 1 per cent., draw through E = 151·5 and

148·5 a line parallel to the abscissa. From Curve I. we see that at no load for a shunt current of $c_m = 16$ the voltage will be 151·5, *i.e.* the maximum permissible. Loading the machine with 150 amps. (Curve II.) its voltage would—with the same exciting current as before, viz. 16 amps.—fall to 144·5, *i.e.* below the minimum permissible. The load with which the machine can be loaded so that its voltage is just the permissible minimum is given by point A. Drawing a dotted curve through this point we get a characteristic which lies between I. and II., and which therefore corresponds to a load been 0 and 150, namely, to 75 amps. Thus in loading the machine with 75 amps. its voltage will fall to 148·5. In order to prevent a further falling of the terminal volts with increasing load we must increase the shunt current, that is, we must cut out part of the shunt resistance. By increasing the shunt current to 17 amps., we increase the voltage to 151·5 volts. If the load is increased to 150 amps. (Curve II.) the voltage will fall to 148·5 volts again. This is repeated until at an overload of 25 per cent., *i.e.* at 750 amps., and an exciting current of 24·8 amps., the voltage falls again to the minimum (148·5 volts).

From Fig. 240 the resistances of the successive steps can now be easily determined. From Curves I.–VI. we see that for a current of

| | | | | | |
|---|---|---|---|---|---|
| 0 | amps. | the shunt current | should be | 16·0 | amps. |
| 75 | ,, | ,, | ,, | 17·0 | ,, |
| 150 | ,, | ,, | ,, | 18·0 | ,, |
| 225 | ,, | ,, | ,, | 18·8 | ,, |
| 300 | ,, | ,, | ,, | 19·8 | ,, |
| 375 | ,, | ,, | ,, | 20·6 | ,, |
| 450 | ,, | ,, | ,, | 21·6 | ,, |
| 525 | ,, | ,, | ,, | 22·6 | ,, |
| 600 | ,, | ,, | ,, | 23·6 | ,, |
| 675 | ,, | ,, | ,, | 24·8 | ,, |
| 750 | ,, | ,, | ,, | 25·8 | ,, |

if the maximum voltage is to be obtained.

From the known resistance of the field coils—in this case $5\omega$—the resistance of the regulator can be obtained. If this is done for the various loads, the difference between successive values of resistance required is equal to the resistance of the corresponding step.

For instance: For $C = 0$, we have, according to formula (62)

$$r_r = \frac{151{\cdot}5}{16} - 5 = 4{\cdot}47\omega$$

For $C = 75$ amps.

$$r_r = \frac{148{\cdot}5}{17} - 5 = 3{\cdot}73\omega$$

For C = 150 amps.

$$r_r = \frac{148{\cdot}5}{18} - 5 = 3{\cdot}25\omega$$

etc.

Thus the first step must have a resistance of $4{\cdot}47 - 3{\cdot}73 = 0{\cdot}74\omega$ the second, $3{\cdot}73 - 3{\cdot}25 = 0{\cdot}48\omega$, etc. In Fig. 240 we also see what currents the respective coils must be designed to carry. Thus the current flowing through the first coil varies from 15·2 to 16 amps.; through the second coil from 16 to 17 amps., etc.

For shunt regulators in which the resistances of the successive steps are not separately determined, the sectional area of the resistance wires depends upon the minimum and maximum shunt current. Taking the case of a machine whose field resistance is $20\omega$, the shunt current with magnets cold for normal voltage and no load is 3·5 amps., and with magnets hot and maximum overload 5 amps. (E = 100). The regulating resistance required for this machine

$$r_r = \frac{E}{c_m} - r_m = \text{about } 8{\cdot}6\omega$$

To make the resistance sufficient for all possible cases we should add 40 per cent., so that the whole resistance becomes about $12\omega$. Obviously the first spirals must be designed to carry about 5 amps. while through the last spirals a current of less than 3·5 amps. will flow. In this case wires of different thickness will have to be used for 3, 4, and 5 amps., and will be distributed on the regulator according to the number of contacts.

In some cases the variation of voltage of shunt generators is also tested. We have seen in Chapter VII. that this can be obtained in two ways. The first method is to bring the machine to the normal voltage, keeping the shunt current and speed constant, and then gradually loading the machine to full load. Let E be the voltage at no-load, $E_1$ the voltage at full load, then the percentage voltage drop

$$e\% = \frac{E - E_1}{E} 100$$

The second method consists of fully loading the machine and regulating the voltage to normal ($E_1'$), keeping the speed and excitation constant. The load is then gradually reduced and finally thrown off, until at no-load the terminal voltage is a maximum (E′). The percentage voltage drop

$$e\% = \frac{E' - E'_1}{E'} \cdot 100$$

As a rule the best brush position is marked on the machine. If the machine is to run sparkless at all loads with fixed brushes, this best position must be found by experiment. This is attained by varying the load from zero to maximum, and observing the position at which the least sparking occurs.

With machines working with variable brush position the best position at no load should first be found and marked. The machine must then be loaded and the brushes moved as required. The best position for full load should also be marked. After reversing the direction of rotation of the machine the best position for full load should again be found and marked. The three positions of the brush rocker should then be marked O, L, and R respectively (O for no load, R for clockwise rotation, L for counter-clockwise, viewed from the commutator).

After the machine has had sufficient time to cool down, it should be run as a motor (light) with normal voltage and excitation, and its speed recorded. This test serves the purpose of disclosing any damage to the winding of the motor which may have occurred during the completion or finishing of the machine. If, after the finish, the machine runs as a motor with the same speed as before, and if there are no signs of excessive heating, it may be assumed that the machine is in good order.

The voltage of shunt generators, for charging accumulators without a booster, must be adjustable within wide limits. For a 110 volt battery a dynamo is generally used, which is wound for a voltage of about 135–140 volts at normal speed. By means of the shunt regulator the voltage must be adjustable to about 65 volts, while at small loads it must rise to about 165 volts. Besides the ordinary tests described above, another test must be made to determine the minimum voltage which can be obtained with the normal current and normal speed without excessive sparking. An examination should also be made to see how far the voltage can be raised by short circuiting the shunt regulator (current about ¼ normal, machine hot). In some cases the field coils of such machines are designed for an exciting voltage of 110, and excited from a battery. For 110 volts the machine works with some resistance in the shunt circuit; for charging the battery the shunt resistance is gradually cut out, so that finally the field is excited from about 150–170 volts. The dynamo voltage can thus be easily raised without increasing the speed.

The actual test with these machines is as follows:—

The current should be kept constant at the normal and the voltage reduced (by inserting resistance in the shunt) until the machine begins to spark moderately. The corresponding voltage should be recorded. Then the voltage should be again increased as

far as possible—current and speed being kept constant. If finally all the field resistance is cut out, *i.e.* the field coils connected to the armature terminals, the voltage will be a maximum for this current. By reducing the armature current the voltage can be made to rise still further, until at no load the maximum voltage will be attained.

For determining the resistance of the shunt regulator it will be essential to know whether the machine is self-exciting or separately excited from a battery. In both cases the shunt current must first be measured at the lowest voltage (no load, field coils cold), and then at the maximum voltage, which will be higher if the machine is separately excited from the battery. From these readings both the resistance and the dimensions of the wire of the shunt regulator can be found.

Boosters should be tested in a similar manner. They work with a varying voltage within very wide limits; and as with full-load current the voltage has to be reduced considerably below the normal, they work with a very weak field. Consequently they should be specially tested with reference to sparkless (or nearly sparkless) running. Boosters are generally separately excited.

## 4. Shunt Motors

The permanent load test for shunt motors is the same as for shunt generators, and the same remarks regarding the measurement of temperature, insulation resistance, and insulating strength hold good.

The special tests for an ordinary shunt motor comprise the determination of its overload capacity and its speed variation.

To determine the former, run the motor first without load, mark the best brush position; then gradually load the motor (if necessary shift the brushes) and mark again the position of the brush-rocker for full load. The load is to be gradually increased to 50 per cent. above normal, and for a very short time (about half a minute) to 100 per cent. above normal, and the behaviour of the motor with regard to commutation to be observed.

As we have seen from the results of experiment No. XIII., the speed of a shunt motor falls generally with increasing load. The speed variation should therefore be determined. For this purpose the speed of the motor should first be measured when running light with normal voltage, and keeping the latter constant note the speed when loaded with normal load; the difference in speed between no-load and full load represents the speed variation. This may also be determined for 50 per cent. overload.

In most cases a speed variation is allowable; in some instances, however, a constant speed at all loads is essential, hence requiring a shunt regulator. If—as it is usually the case—the speed drops with increasing load, it can be compensated by inserting some resistance in the shunt circuit, namely, by weakening the field. The regulator may be worked automatically or by hand.

In determining the resistance of the shunt regulator we must take into account that the speed of a shunt motor when cold is smaller than the speed at the same load when hot; the reason being that for constant terminal voltage the resistance of the cold field coils is smaller, and consequently the shunt current larger than when the coils are hot. For normal value, therefore, the speed which the motor assumes when running light with the field coils hot is to be taken.

To determine the total resistance of the regulating resistance required, the motor should first run light (field coils hot)—the speed with normal voltage being considered as the normal. After the machine has cooled down the motor should be loaded with the particular load for which the speed is still to be kept constant, and the shunt current weakened until the speed is normal. The shunt current ($c_m$) should be recorded. From this current and the (measured) field resistance the regulating resistance may be found by formula (62). It is recommended to add here also about 15–20 per cent. to the calculated resistance.

If the speed variation is not to exceed a certain amount ($\pm n$ per cent.) the resistances of the successive steps must be determined as in the case of a shunt generator. For this determination part of the curves indicating the speed as a function of the exciting currents at various loads must be found (see Curves I.–V., Fig. 130). From the maximum and minimum speeds specified and the known field resistance the resistances of the successive steps can be determined in exactly the same manner as has been shown for a generator.

With motors for variable speed (effected by varying the excitation) a test must be made to observe the commutation for all specified speeds, and also for a speed somewhat in excess of the maximum specified speed. These tests must be made with the machine fully loaded.

For speed regulation of a shunt motor below the normal, resistance is inserted in the armature circuit—the excitation remaining constant. To determine this series resistance, the relation between speed and terminal voltage of the motor at a given load must be known. Let the speeds be $n$ and $n'$ respectively, the E.M.F. in the armature $e$ and $e'$, and the respective terminal voltages E and E', then, assuming a constant exciting current—

$$n : n' = e : e'$$

and, since $e = E - Cr_t$ (C = armature current, $r_t$ = total armature resistance)

$$n : n' = E - Cr_t : E' - Cr_t$$

By this formula the terminal voltage E′ necessary to produce a speed $n'$ can be found, if the normal speed $n$ and the normal terminal voltage E be known.

We have

$$E' = \frac{n'(E - Cr_t)}{n} + Cr_t \quad . \quad . \quad . \quad . \quad . \quad . \quad (63)$$

In calculating the series resistance it is essential to know whether the speed is to be reduced to $n'$ at all loads or for a certain load only. In the former case the requisite resistance will obviously be larger than in the latter case. If the speed is to be reduced to $n'$ at any load, then the resistance

$$r_s = \frac{E - E'}{C_l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (64)$$

where $C_l$ stands for the no-load current of the motor, or else for the minimum current at which the motor speed is still adjustable to $n'$ revolutions.

The regulation of speed of a shunt motor above the normal is effected by weakening the field. To estimate the necessary shunt resistance, the shunt current ($c'_m$) of the motor should first be measured at no-load and normal speed (field coils cold); then the machine is loaded and the shunt current weakened until the maximum speed required is reached and again $c_m$ recorded. From $c_m$ and the field resistance $r_s$ is found as usual. When determining $c_m$ the behaviour of the motor with regard to commutation should also be observed.

## 5. Series Generators

Series generators are constructed for special purposes only. With regard to the general tests, see Chapters VI.–IX.

Besides the load, overheating, and the insulation tests the characteristic should always be determined, *i.e.* the terminal voltage as a function of the load with constant speed. Apart from these tests series generators should always be tested in the same manner as they are worked, *i.e.* either with constant current and variable voltage (Thury's system) or with variable current and variable voltage.

## 6. Series Motors

The field of application of series motors is very wide. They are used for all kinds of elevators, cranes, lifts, etc.; for the direct transmission of power and for traction purposes. Series tram motors will be dealt with in the next chapter.

For most of the above purposes, series motors for constant terminal voltage are used, and only these will be referred to in the following.

First a few points of the characteristic should be determined (machine cold) and the total resistance (armature + field) measured. The machine must then be loaded with normal load and the speed recorded. The latter varies with the temperature of the machine, *i.e.* with the time of run. Hence during the load test the speed should be measured at regular intervals and recorded. If the current is kept constant, the stationary state of temperature can be observed from the speed. The characteristic should next be determined for currents up to 50 per cent. above normal.

Since series motors are frequently employed for intermittent work, the output of the machine will vary, according to the length of the intervals in which the machine can cool down. As the output is mainly limited by the temperature rise, the determination of the latter requires extra care in the case of series motors. The temperature rise should be determined for various loads. From these experiments the temperature rise can be found for any load, which is important in determining the output of motors working for short intervals only.

To find the capacity curves for a given overheating proceed as follows: Run the motor with a small load, say $\frac{1}{4}$ normal, and measure its temperature at intervals of about 15 minutes. The machine must work with this load, until its temperature is about 50° C. above that of the surrounding air. If the time of working is plotted as abscissa, and the corresponding rise in temperature as ordinate, the temperature curve so obtained is for the particular load under which the motor was working. Similar curves may be determined for say $\frac{1}{2}$, $\frac{3}{4}$ normal, and $1\frac{1}{2}$ times normal load. From the temperature curves it is seen that the time of run must be shorter the larger the load, otherwise a certain temperature rise will be exceeded.

Examples of temperature curves are given in Figs. 241 and 242. These curves are those of a completely enclosed crane motor. Fig. 241 gives the temperature curves for 8, 11, 14, 18, and 22 amps. respectively. For each of these loads three curves are given; the lower full line represents the rise of temperature of the magnet coils, the upper the rise of the armature temperature, and the dotted line the rise of the air temperature prevailing in the interior of the motor above that

of the surrounding atmosphere. The temperature of the air prevailing in the interior of the motor was measured by a thermometer inserted through a hole in the case, the bulb being 1 inch above the middle of the armature between the two pole pieces. From the curves we see that this temperature lies with all loads (except the maximum) between the temperatures of the armature and the field. From the curves in Fig. 241 the curves I. and II. in Fig. 242 have been derived. Curve I. refers to a temperature rise of 50° C., Curve II. to 40° C. These curves are obtained by drawing in Fig. 241 through the ordinates 40° and 50° respectively parallels to the abscissa, and plotting the abscissæ of the points of intersection with the various curves as

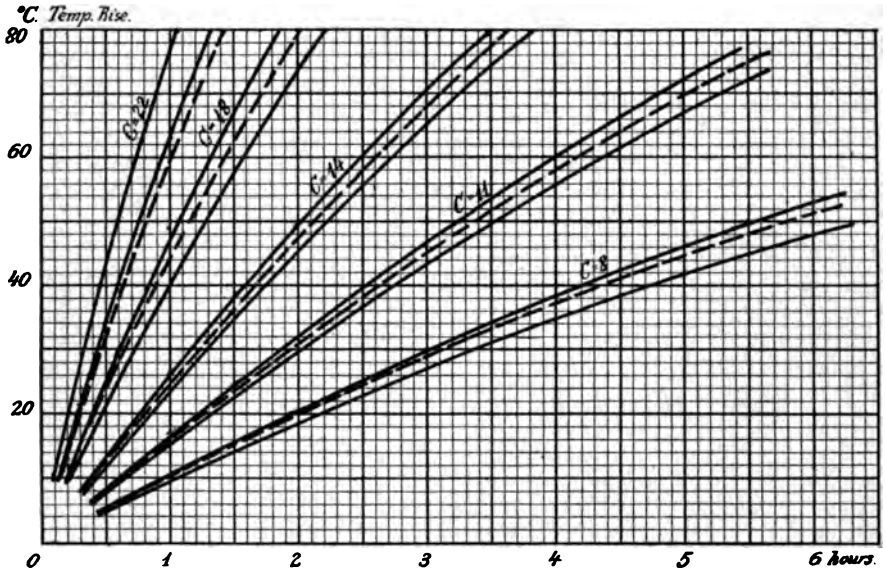



FIG. 241.

functions of the respective loads. In Fig. 242 the armature temperatures are only considered.

With motors for lifts, cranes, etc., the turning moment or leverage for a certain current is sometimes desired. This leverage or force acting at a radius $r$ may be found either by calculation or experiment. In the first case the efficiency of the motor or its output in B.H.P. as a function of load must be known. The output of a motor in B.H.P. is

$$L_{B.H.P.} = \frac{2r\pi n P_{kg}}{60 \cdot 75}$$

or

$$L_{B.H.P.} = \frac{2r\pi n P_p}{33,000}$$

where $P_{kg}$ and $P_p$ stand for the force in kgs. or lbs. acting at a radius of $r$ metres or feet respectively.

From this formula P can easily be found.

In Fig. 243 Curve I. represents the output in B.H.P. as function of the current of an enclosed crane motor. From this curve, and the characteristic (Fig. 244) of the motor, the tangential force P has been

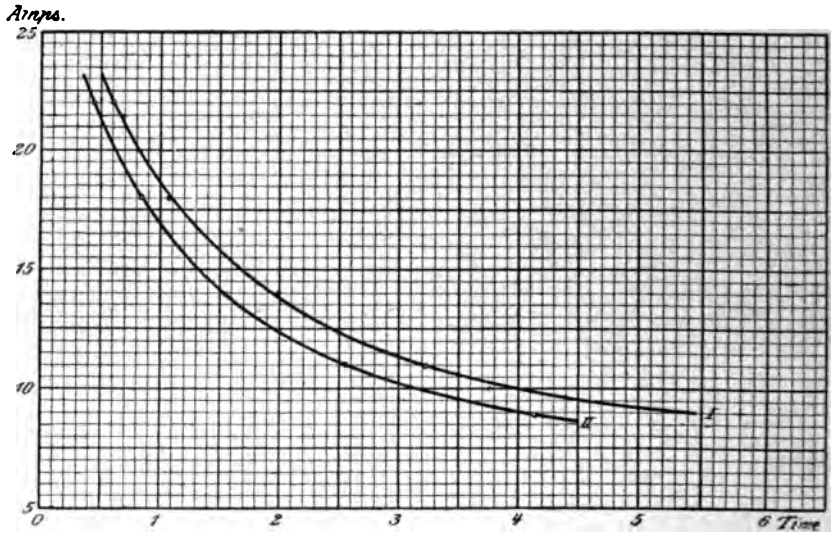



Fig. 242.

calculated, and plotted as Curve II. in Fig. 243 (force in kg. acting at a radius of 1 m.) as a function of the current.

The tangential force of a motor can also be measured directly by any of the brakes described in Chapter IX. As a matter of fact with all these brakes the tangential force is really the quantity measured, and from this (and the speed) the output is found by calculation.

For measuring the starting effort of a motor, the lever of the brake is loaded with a weight, the brake then tightened, and the motor switched in series with sufficient resistance. By gradually cutting out the latter the current is increased until the motor just starts to rotate, when the current should be immediately switched off.

It is better still to provide the end of one lever with a weight and that of the other lever with a spring (see Fig. 168). In this case

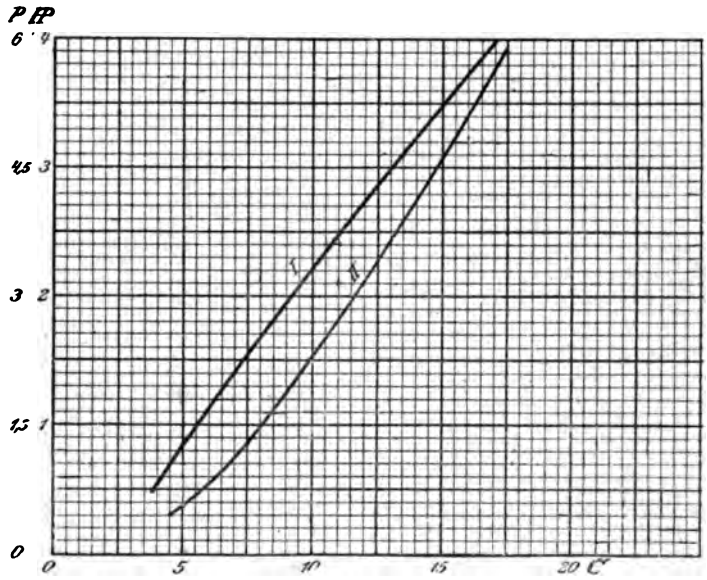



FIG. 243.

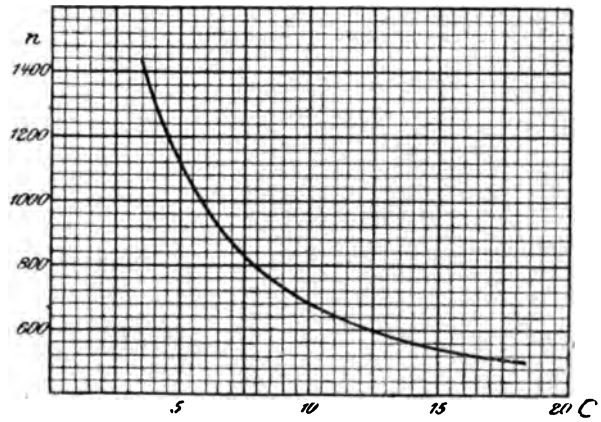



FIG. 244.

$P = P_1 + P_2$, where $P_1$ represents the weight, $P_2$ the reading on the spring (both of course in similar units).

## 7. Tram Motors

Generally a group of tram motors of the same size and type have to be tested at the same time. It is then necessary to subject one

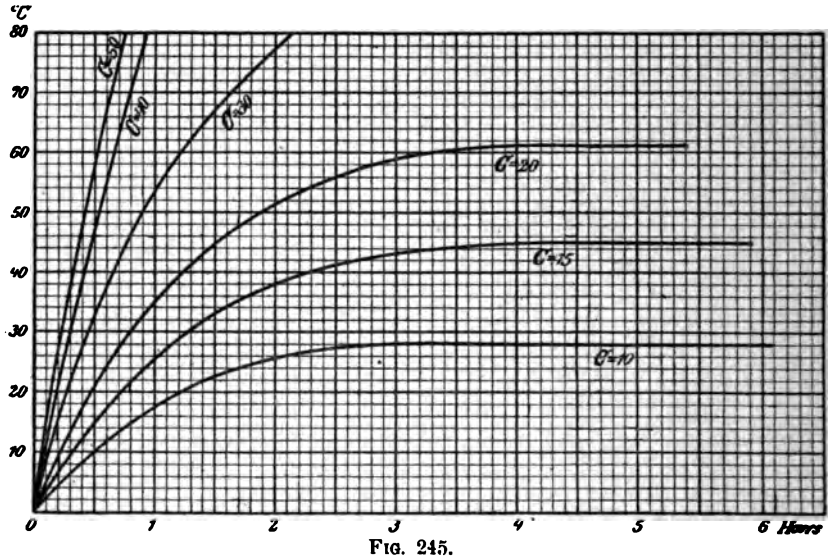



FIG. 245.

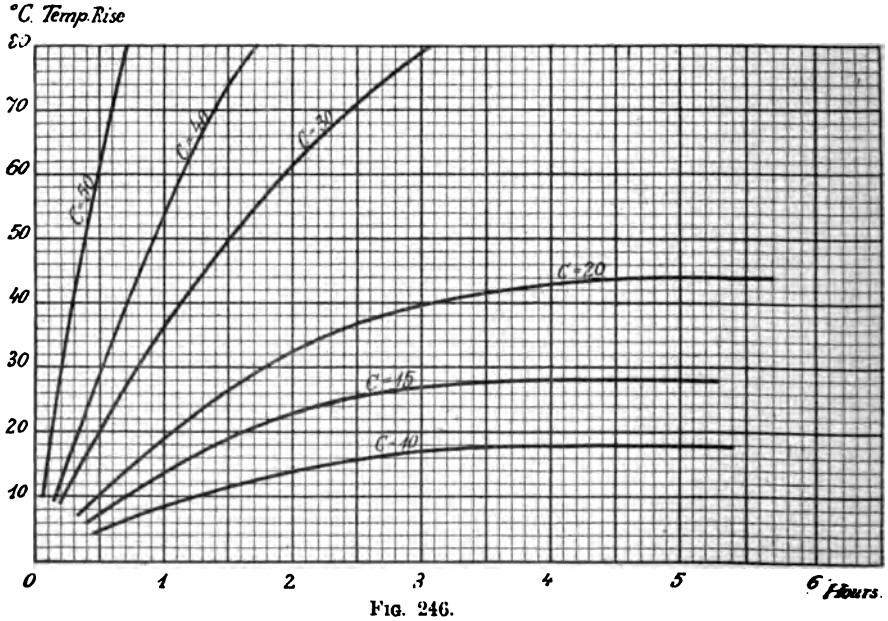



FIG. 246.

or two of the motors to a thorough test, and all the others are subjected to a load test only. It is also noted if the other motors behave

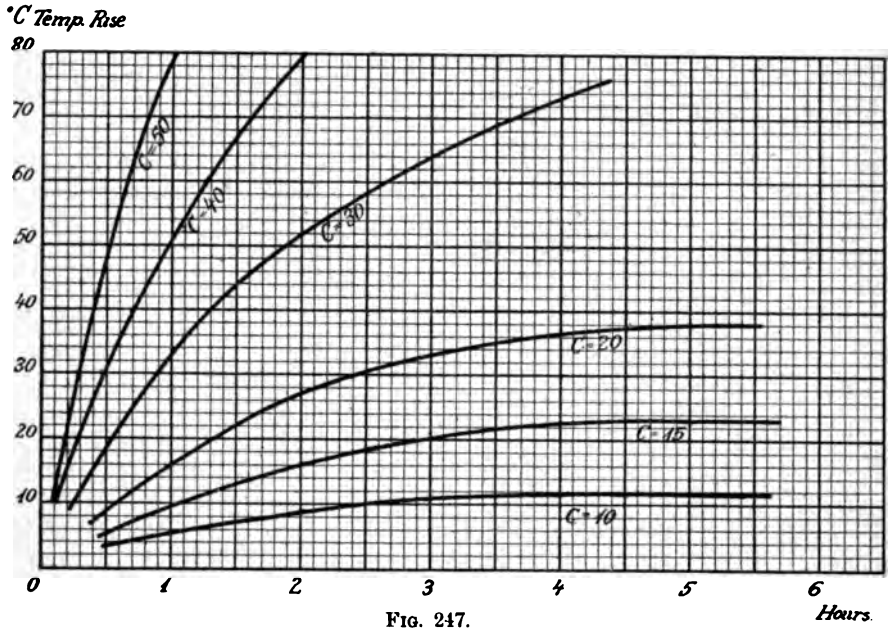



FIG. 247.

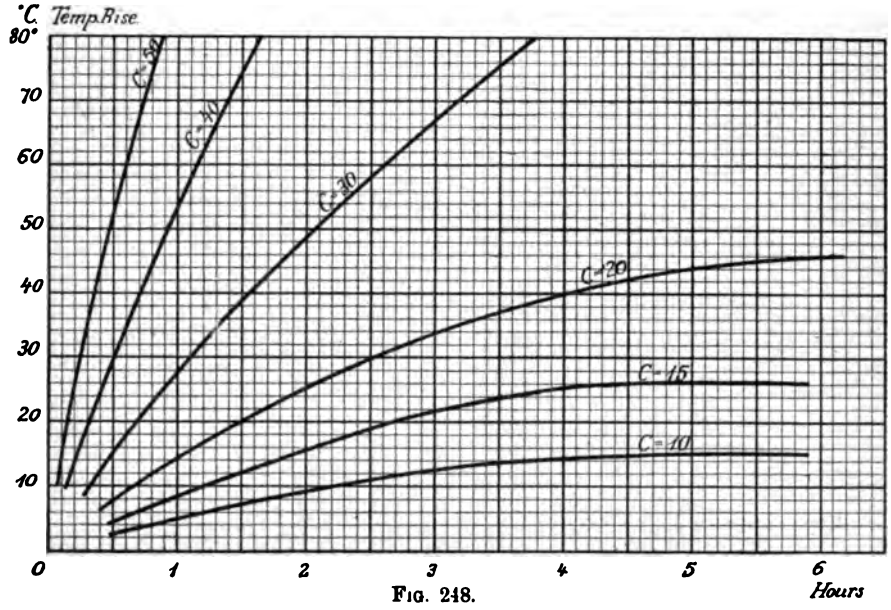



FIG. 248.

equally with regard to commutation and overheating as the thoroughly tested motors. If this is the case the motors are in order. If, however, any of the motors differ in speed, overheating, etc., from the motors considered as standards, they must be tested completely and the cause of the difference discovered.

The exact test of one or two motors of the group should be practically the same as that of an ordinary enclosed series motor. Special stress must also be laid upon the exact determination of the temperature curves; as an example for these tests four series of curves are given below. They are the results of the temperature tests on a 25 B.H.P. tram motor. Fig. 245 shows the temperature rise of the armature (measured by the indirect method); Fig. 246 the same measured by thermometer. Figs. 247 and 248 refer to the field magnets, the curves in the former having been obtained by the indirect method, those in the latter by thermometer.

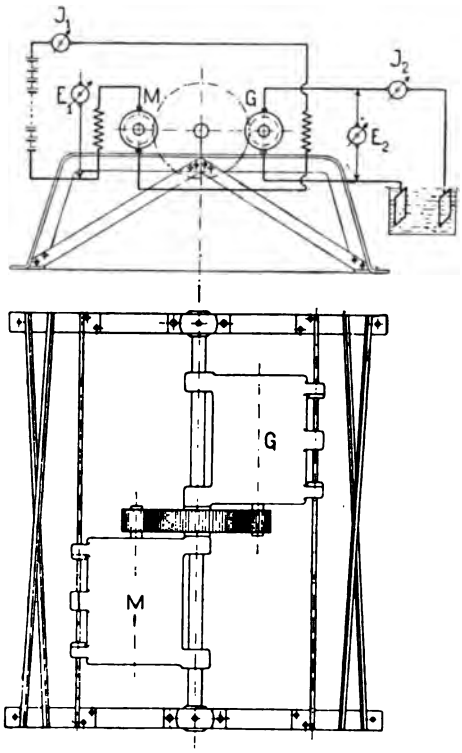



Fig. 249.

Apart from the temperature and load tests the following tests should also be made with tram motors: The external characteristic and the efficiency. The latter should be determined by means of a brake and also in the way described below; it is also recommended to make a test for the separation of losses with one or two of the motors. The starting effort as a function of the current should also be determined by experiment.

For testing the whole group of motors it is best to fix them on a special stand, as shown in Fig. 249. One machine then always works as a motor and drives the other as a generator. In this way the efficiency can be found, assuming that the efficiencies of

the two machines are alike. For comparative tests, however, this arrangement is quite sufficient.

The standard motors should first be tested on this stand, and the results of the test of all motors compared with those of the standard motors.

## 8. Compound Generators

The shop test of a compound generator scarcely differs from that of a shunt generator. During the voltage test, which has to be made after the machine has been heated up, the lever of the shunt regulator must not be moved, *i.e.* the shunt current, once adjusted, must be kept constant.

As already mentioned, compound generators are nearly always provided with shunt regulators; they serve the purpose of compensating the difference in resistance of the cold and hot field coils; besides, the shunt winding is frequently designed with extra turns, so that even with hot field coils a small resistance remains in the shunt circuit.

The resistance required for the shunt regulator is determined in exactly the same manner as has been described for a shunt machine. Thus with the machine cold and unloaded (speed and voltage normal) the shunt current should be measured, and from this current and the known field resistance the regulating resistance is deduced by calculation.

# APPENDIX

## THE INSTALLATION, CARE, AND MAINTENANCE OF ELECTRIC MACHINES

THE place of installation of an electrical machine should be as dry and cool as possible, and free from dust. The foundation of the machine should be as solid as possible, and the machine so fixed that the commutator and brushes are easily accessible. If the machine is driven or is driving another by means of a belt, slide-rails should be provided for the adjustment of the same.

The speed of the prime mover of an electric plant should be as uniform as possible, as the smallest variation in speed of the dynamo would produce a fluctuation of the dynamo voltage. The irregularity during one revolution should not exceed 0·5 per cent. The regulation of the prime mover must be a good one, so that the voltage can be kept constant at the various loads. The difference in speed between no load and full load should not exceed 3 or 4 per cent.

The prime mover and generator can be either built on one shaft, coupled directly together or connected by means of a belt. In the latter case the belt should be of uniform thickness throughout; preferably it should be an endless belt, or if not the joint should be very carefully laced so as to make it as straight and smooth as possible. The axes of the prime mover and generator should be parallel so as to ensure a true running of the belt. Short or vertical belts should be avoided, as with these the slip is considerably larger than with long or with horizontal belts.

The bearings of electrical machines are generally arranged for oil lubrication. Light brass rings are suspended on the shaft and dip in oil in a reservoir underneath. By the motion of the shaft the rings are set into rotation, thus supplying the brasses with oil. The latter flows through the brasses and back again into the oil reservoir, so that a continuous circulation of oil is maintained when the machine is running. Before starting a machine for the first time it is advisable to clean the bearings with paraffin or benzine. The latter should flow

through the brasses into the oil reservoir, from whence it can be tapped off together with the dirt collected. Next, the reservoir should be filled with the proper lubricating oil up to the mark on the oil gauge. The machine should then be started, and through the hole usually provided on the top of the bearing the motion of the oil-rings should be observed. After a run of several hours the bearings should not be more than hand-warm. An excessive heating of the bearings indicates that the oil-rings do not work properly, or that there is some dirt in the bearings, or that the belt is too tight. If, notwithstanding a continuous supply of fresh oil to the shaft and a slackening of the belt, the excessive heating should continue, the machine must be stopped, the armature taken out of the machine, and the shaft and brasses cleaned, and, if required, refitted.

About once a week the oil reservoir should be filled up to the gauge mark, and once a month the oil should be taken out and filtered before re-using, or, better still, should be replaced by fresh oil.

The commutators of continuous current machines must always run true, and the brushes must not shake or rattle. Eccentric commutators must be tightened when hot, turned off, and polished. The commutators of large machines should be ground when running at full speed by means of an emery-wheel, and finally polished with glass-paper; on no account should emery-paper be used. Commutators should occasionally be lubricated with a few drops of oil applied either with the finger or with a non-fluffy cloth.

With small machines the brush-rocker is generally made movable, and can be fixed in position by a screw in the handle or by a small locking screw. With large machines a worm and worm-wheel adjustment is generally used. The approximate brush position is generally indicated by marks on the brush-rocker and bearing. The exact position of the brushes is that which shows the least tendency to spark. To find this position—with a generator give a forward "lead," with a motor a backward "lead," to the brushes.

The brushes used for electric machines are made of carbon, copper gauze, or of very thin folded metal foil.

With metal brushes far higher current densities are allowable than with carbon brushes; the latter, however, have a lesser wearing effect on the commutator and require less shifting with varying load than the former. Flat metal brushes must be inclined in the direction of rotation of the commutator. If the commutator were run against the brushes, the pressure would tend to buckle the brushes and thus damage the commutator segments. After fixing the brushes in the inclined position they should be examined to see if the pressure on all the brushes is the same and not excessive. Each brush-holder pin generally contains several brushes, with very small machines only one brush per pin is provided. If there are several brushes on one

pin the single brushes may be lifted during running for the purpose of cleaning and adjustment. Under no condition whatever must all the brushes on one pin be lifted simultaneously, as this would invariably burn the commutator and brushes. All the brushes belonging to one pin should be perfectly in line, *i.e.* they should cover the same commutator segments.

The treatment of the commutator and carbon brushes and the quality of the latter will have a great influence on the sparkless running of a continuous current machine. The different sorts of carbon brushes show great differences in quality, hardness, and conductivity, so that a machine will work best with a particular sort of brush. Generally speaking, machines for high voltages will work best with hard carbons, while for low voltage machines soft carbons are more suitable.

The brushes on the different pins must be spaced so as to cover the whole commutator surface. The distance between the tips of the different sets of brushes should be—

for 2-polar machines equal to $\frac{n}{2}$

" 4- " " $\frac{n}{4}$

" 6- " " $\frac{n}{6}$

etc.,

where $n$ is the number of commutator bars.

After the adjustment of the carbon brushes they should be ground in. For this purpose a piece of glass-paper should be inserted between the commutator and the brush, and the brush contact shaped by pulling the paper backwards and forwards.

Before starting the machine the dust should be blown out by a hand-blower, and the commutator cleaned with a few drops of oil. All nuts and loose connections should be tightened up and care taken to provide sufficient oil in the bearings and to ensure that the tension of the belt is not too great. While the machine is running the oil-rings should be observed and the temperature of the bearings tried by hand. The brushes should be adjusted so that the machine does not spark.

After the machine has been stopped any dust produced by the brushes should be blown off and the temperature of the iron parts, the windings, bearings, and commutator should be tried by hand. With regard to the overheating of the machine the following should be borne in mind: If a generator is running with full excitation so as to give its normal voltage but without load, the overheating of the magnet coils,

yoke, and armature core (which depends practically on the excitation only) will be near to the limit of the overheating of the machine. It will increase but little with the machine fully loaded, as the additional overheating due to the armature current is generally not considerable. Thus from the overheating of these parts of the machine at no load a wrong conclusion of the additional overheating at full load is frequently formed.

The output of a dynamo, *i.e.* the product of its voltage and current, is limited by the mechanical and electrical stresses permissible. No machine should be continuously worked at a higher load than that for which it was built, as a permanently overloaded machine may become so hot as to endanger the insulation of its windings.

Every machine is also built for a certain armature speed which should not be exceeded. Generally a name-plate is provided on which the maximum speed and the corresponding current and voltage are given. It is advisable, even with the smallest plant, to provide the machine with an ammeter and a voltmeter so as to be able to check the load of the machine at any moment.

If a continuous current generator does not excite itself when started for the first time after its installation, *i.e.* if it gives no voltage, then its direction of rotation is wrong. If this cannot be altered the brush-rocker should be moved through 180° with 2-polar machines, 90° with 4-polar machines, 60° with 6-polar machines, etc. In this case a series, shunt, or compound generator will properly excite itself, and the polarity of the machines will in all cases be the same as under the original conditions.

When starting a shunt generator the main switch should first be opened and the lever of the shunt regulator moved to the first contact; thus the whole shunt regulating resistance is inserted in the shunt circuit. When the armature has attained its full speed the arm of the shunt regulator is moved to the right until the machine attains its normal voltage. Afterwards the main circuit is closed by quickly closing the main switch. For stopping the generator proceed in the opposite way, *i.e.* open the main switch quickly and then gradually decrease the voltage by moving the arm of the shunt regulator to the left until finally the field circuit is broken. If several dynamos are working in parallel on a common bus-bar the procedure is as follows: For switching a dynamo in circuit its voltage must first be brought to that of the bus-bars, after which the main switch is closed. The dynamo will at this moment supply a small current only, which can be gradually increased by increasing its shunt current. For stopping the dynamo, the shunt current should be gradually decreased until it supplies a small current only or none at all. The main switch can then be opened.

Series dynamos must be started with a closed main circuit. For

stopping a series dynamo its speed is gradually decreased without opening the main circuit.

For starting and stopping a compound dynamo proceed as with a shunt generator. The series and shunt windings must assist each other. If a compound generator does not excite itself (wrong direction of rotation), both the main cables and the shunt connections are to be changed over; the polarity will then be the same as with the original conditions.

According to the connections between the armature and field winding, we distinguish three types of direct current motors, viz. shunt, series, and compound motors. Each of these types has its own advantages and disadvantages, and consequently its own sphere of application.

Shunt motors are used when a constant speed is desired at various loads, and when during brake periods the motor should run as a generator supplying current to the network.

Series motors are employed where great starting torques are required and when there is no possibility of the motor running away, for example, tram motors, crane motors, etc.

Compound motors are used where quick starting is required, but *not* for the purpose of keeping the speed constant.

Slide-rails should be used with motors as with generators, to adjust the tension of the belt. Smaller motors are directly bolted down in position.

Moving the brush position by an amount equal the pole-pitch will have the effect in all three types of reversing the direction of rotation. Changing the mains, however, does not reverse the direction of rotation of either type.

With regard to the commutator, bearings, and brushes, the remarks under generators apply here equally well.

Motors up to an output of 1 B.H.P. do not require a special starting arrangement, but can be simply switched in and out of circuit by an ordinary double-pole switch. For large motors, however, special starting devices are required, as otherwise a great rush of current would occur which would cause a fluctuation of the voltage and might easily destroy the motor armature.

For starting a shunt motor a starting resistance is inserted in the armature circuit, which is gradually cut out as the speed of the motor increases. The connections of the starter are such that in starting, the armature current is weakened while the full shunt current flows through the field. In breaking the motor circuit the armature and field are automatically connected in series so that the current due to the self-induction in the field winding can flow through this closed circuit.

For regulating the speed of a shunt motor a resistance is generally

inserted in the field circuit by means of which the shunt current can be regulated. A weakening of the field current causes an increase, and a strengthening a decrease of the speed. To alter the direction of rotation the shunt connections should be changed.

In the starting of series motors there are two cases possible; either one generator supplies the current for one motor only, or the motor is connected to a constant voltage supply. In the first case the motor is generally started from the generating station. The motor is permanently connected with the generator; if the latter is started the former will start too. For stopping the motor, the generator speed is gradually decreased and finally stopped.

In the second case the motor is started and stopped by means of a starting resistance, in the same way as a shunt motor.

The speed of a series motor may be varied by means of a resistance connected in parallel with the field winding. The smaller this resistance, the higher the speed of the motor. The direction of rotation can be reversed by changing the cables leading to the brushes.

Compound motors are started, stopped, and regulated in the same way as shunt motors. The series and the shunt turns must assist each other. To change the direction of rotation—change the cables leading to the brushes, and the shunt connections.

# TEST-SHEET FOR CONTINUOUS CURRENT MACHINES.

Date _ 19_

Dynamo-Motor Type

Field No. S. O. No.___Type Pole Series, Shunt, Compound,

Armature No. S. O. No. Type Winding

Brush-holder Type Brush Pins Brushes p. Pin Brush

Size_____ Amps. Volts R. P. M.

Customer: Special Instructions

Remarks:

**Test-Record:** Start End_____Hours

| Time. | R. P. M. | Amps. | Volts. | Shunt Amps. | Shunt Volts. | Series Amps. | Series Volts. |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Commutation

Remarks:

Curves, see Book No. Page

Temperature ° C.-Air Comm. Arm. Copper___Arm. Iron

Insulation (A.C.) Armature_____Series Field Shunt Field

Remarks:

Tested by Mechanical Inspection by

Approved

## Temperatures °C.

| | |
|---|---|
| Air | |
| Commutator | |
| Arm. Copper | |
| Arm. Iron | |
| Series Winding | |
| Shunt Winding | |
| Field Iron | |

# TEST-SHEET FOR RAILWAY MOTORS.

Date _____ 19 __

Type of Railway _____

Field No. _____ S. O. No. _____ Type, laminated Pole _____ Series _____

Armature No. _____ S. O. No. _____ Type _____ Winding _____

Brush-holder Type _____ Brush Pins _____ Brushes p. Pin _____ Brush _____

Size _____ Amps. _____ Volts _____ R. P. M. _____

Special Instructions _____

**Test-Record:** Start _____ End _____ Hours _____

| Time. | R. P. M. | Amps. | Volts. | Field Voltage. |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Remarks: _____

Curves, see Book No. _____ Page _____

Temperature °C.-Air _____ Field _____ Arm. _____ Comm. _____

Insulation (A. C.) Field _____ Arm. _____

Voltage to Earth: Before test _____ After test _____

Highest Revolution _____ R. P. M. _____

Remarks: _____

Tested by _____ Mechanical Inspection by _____

Approved _____

## Temperatures °C.

| | | | | | |
|---|---|---|---|---|---|
| Air | | | | | |
| Commutator | | | | | |
| Armature | | | | | |
| Field Iron | | | | | |

Generator/Motor Type_____ Machine No._____

Voltage_____ Current_____ Amps., output_____ K.W./B.H.P

Revs. per Min._____ Consumption_____ B.H.P./K.W.

| | $E_a$ | $E_m$ | $C_a$ | $C_m$ | $n$ |
|---|---|---|---|---|---|
| Load { Magnets short-circuited . . | | | | | |
| Load { normal . . . . . | | | | | |
| No load { Magnets short-circuited . | | | | | |
| No load { at normal voltage / at normal speed } . . . | | | | | |
| Running light as motor . . . . . | | | | | |

Time of load_____ Hours.

Armature—Resistance measured on the Commutator { cold_____ hot_____

" Resistance measured on the Terminals { cold_____ hot_____

Field Resistance . . . . . { cold_____ hot_____

Temperature—Rise of Armature _____

" " Commutator_____

" " Field-coils_____

Air-gap_____

Insulation_____

Displacement of Brushes_____

Sparking_____

Book No._____ Page_____

Remarks:_____

Type _____ No. _____ No. of Poles _____ No. of Field-coils _____

Connection _____ Generator / Motor _____ Watts / B.H.P. _____ Volts. / Amps. _____ Revs. per Minute.

Direction of Rotation (seen from the Commutator): _____

No. of Brush-holder Pins _____ with _____ inches diameter.

Delivered with _____ Brushes per pin { Width _____ Thickness _____ Length _____

Pulley: Diameter _____ Width _____

**O. S. No.** _____ **Order:** _____

Drawings: _____

Remarks: _____

## Test.

Made on the _____ after _____ hours run _____

How loaded _____

Instruments used: _____

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Revs. per Minute | | | | | | | | | | | | |
| Terminal Voltage | | | | | | | | | | | | |
| Field Voltage | | | | | | | | | | | | |
| Armature Current | | | | | | | | | | | | |
| Field Current | | | | | | | | | | | | |
| Additional Resistance in Field Circuit | | | | | | | | | | | | |
| Sparking | | | | | | | | | | | | |
| Displacement of Brushes | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

Armature Resistance at ___° C. ___ω, Field Resistance at ___°C. ___ω.

„ ___° C. ___ω, _____ „ ___°C. ___ω.

Shunt Regulator _____ ω.

Tested with _____ Brushes, _____

Temp. of Armature ___° C., of Field-coils ___° C., of Commutator ___° C.,

of Pole-tips ___° C. (measured after _____ hours run) _____

Insulation _____ Tested with _____

# TEST SHEET—DIRECT CURRENT MACHINE.

Date,_____190 __

Motor: Type_____

Field No.____ S. O. No. ____Type____ Poles____ Series, Shunt, Compound

Armature No. ____ ____S. O. No. ____Type ____Winding ____

Brush-holder: Type____ ____ Arms. Br. per Arm. ____Brush ____

Rating: Size ____Amps.____ ____Volts ____ ____R. P. M. ____

Customer_____Elec. Spec._____

Remarks: _____

**Record of Test:** Start_____ ____End _____ ____Hrs. _____

| Time. | R. P. M. | Amps. | Volts. | Shunt Amps. | Shunt Volts. | Series Amps. | Series Volts. |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Commutation ____

Remarks:_____

Balance ____ End play ____ For Curves, see Book ____ ____Pages____

Temperatures ° C.-Air ____Comm. Arm. Copper Arm. Iron

____ Se. Field ____ ____ Sh. Field ____ Field Iron____

Insulation (A.C.) Armature____ ____ Series Field ____ ____Shunt Field____

Remarks:_____

**Next:** _____

Test by Mechanical Inspection by_____

Approved: _____

## Temperatures ° C.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Air | | | | | | | | | |
| Com. | | | | | | | | | |
| Arm. Copper | | | | | | | | | |
| „ Iron | | | | | | | | | |
| Field Series | | | | | | | | | |
| „ Shunt | | | | | | | | | |
| „ Iron | | | | | | | | | |

# INDEX


A

Accumulators, 29
Air-friction, 209
Armature reaction, 102
Armature resistance, measurement of, 31
Armature temperature, measurement of, 51
Auxiliary motor, calibration of, 191

B

Back ampere-turns, 102
Bearing friction, 207
Brake, Brauer's, 172
Brake, Hubert's, 174
Brake, Rieter's, 184
Brake, Wettler's, 172
Brakes, magnetic, 181
Brakes, mechanical, 170

C

Cables, 10
Cables, connection of, 1
Cable shoes, 10
Capacity of resistance wires, 18
Cell switches, 30
Characteristic, external, of a series dynamo, 130
Characteristic, external, of a shunt dynamo, 111
Characteristic, internal, of a shunt dynamo, 132
Compound dynamos, characteristic of, 145
Contact resistance, 40
Cross ampere-turns, 102
Cut-outs, 9

D

Deprez instruments, 25
Dynamometer, 28

E

Eddy currents, 203
Eddy-current brake, 181
Efficiency, the, 163
Efficiency, commercial (total), 167
Efficiency, electrical, 164
Efficiency, mechanical, 164
Electro-dynamometer, 28
Electromagnetic instruments, 23
Electrometer, 29

F

Field curves, 155
Field resistance of compound machines 48
Field resistance of series machines, 48
Field resistance of shunt machines, 48
Fishinger's dynamometer, 180
Friction laws, 208

G

Glow-lamp resistances, 21
Goldschmidt, 154
Gyrometer, 70

H

Hand tachometer, 67
Hot-wire instruments, 29
Hopkinson method, 238
Hubert's brake, 174
Hysteresis, 201

I

Indirect method for determining efficiency, 199
Indirect method for determining resistances, 35
Indirect method for determining temperatures, 50

K

KELVIN'S regulator, 13

L

LIQUID resistances, 21
Liquid starters, 22
Load diagram of a series dynamo, 130
Load diagram of a series motor, 137
Load diagram of a shunt dynamo, 103
Load diagram of a shunt motor, 121
Load diagrams, 101
Loading resistances, 16
Losses, additional, 232
Losses due to bearing friction, 207
Losses due to brush friction, 209
Losses due to eddy currents, 203
Losses due to hysteresis, 201
Losses due to ohmic resistance, 199
Losses, magnetic, 201

M

MAGNET inductor, 59
Magnetic brakes, 181
Magnetic leakage, 154
Magnetic measurements, 154
Magnetization curve, 76
Measurement of insulation resistance, 55
Measurement of resistance, 31
Measurement of speed, 64
Measuring instruments, 23
Mechanical brakes, 170
Mechanical losses, 207
Metal resistances, 16
Methods of loading dynamos and motors, 16

N

NEEDLE galvanometer, 24
No-load diagram of a shunt motor, 91
No-load diagram of a shunt dynamo, 73
No-load diagrams, 72

O

OHMMETER, 57
Over-compounding, 149

P

POTENTIAL curves, 161
Prony's brake, 170

Q

QUICK-BREAK switch, 4

R

READING of instruments, 3
Regulating resistances, 16
Resistance measurements, 31
Resistance wires, 17
Resistances, liquid, 21
Resistances, metal, 17
Rheostats, 16

S

SELF-EXCITATION of series dynamos, 135
Self-excitation of shunt dynamos, 95
Separation of losses by Dettmar's method, 253
Separation of losses by means of an auxiliary motor, 245
Separation of losses by the "inertia" method, 267
Series dynamos, 130
Series motors, 137
Sources of E.M.F., 29
Speed counter, 65
Speed diagram of a shunt motor, 91
Starters, liquid, 22
Starting resistances, 19
Stray coefficient, 154
Stroboscopic method for measuring speeds, 71
Switches, 4

T

TACHOMETER, 67
Temperature coefficient, 17
Temperature measurements, 49
Thermo-cells, 50
Thomson's Double Bridge, 39
Tram motors, 308

V

VOLTAMETER, 23
Voltmeter cable, 10
Voltmeter switch, 5

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